

# High Quality Wave Generator Design using a Smooth Particle Hydrodynamic Method

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## **Abstract**

A smoothed particle hydrodynamic model (*SPHysics, Dalrymple et al., 2007*) has been used to study and improve an initial wave generator design aimed to create high quality surfing waves in inland pools.

A first scale model was built. Several issues in terms of wave quality appeared after the first physical model experimentations. Secondary waves and turbulent surface were affecting the main wave quality. Systematic velocity profile analyses have been carried out. Several assumptions led to a range of proposed designs.

The ultimate wave generator design was finally found to be a constant width discharge slot with a thicker front wall and rounded bottom wedge. The design has been built in ASR's physical laboratories. Experimentations confirmed the numerical model results. The patented SurfPools wave-maker is now able to continuously generate clean wave in a closed basin, optimising energy conversion.

## **Initial Design**

Previous physical model tests were performed at the ASR's physical laboratory in Raglan, NZ. The generator piston (Figure 1) is designed to move vertically, discharging water in the tank through a rounded slot. The main idea is to instantaneously provide fluid particles a post-shoaling wave trajectory.

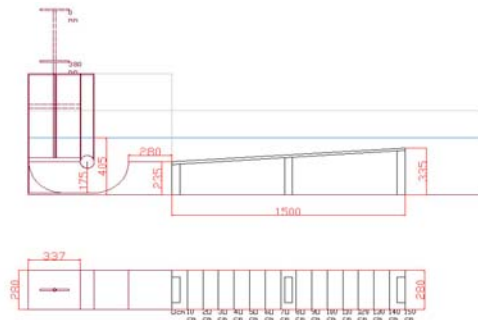


Figure 1: Initial wave tank design

The same wave generator design was simulated (Figure 2) with a two dimensional version of the SPH model. The original code has been modified to allow vertical paddle motion. The free surface evolution in the tank was analysed and compared with the physical modelling snapshots. A qualitative calibration has been carried out to match similar free surface deformation between numerical and physical models (Figure 3)

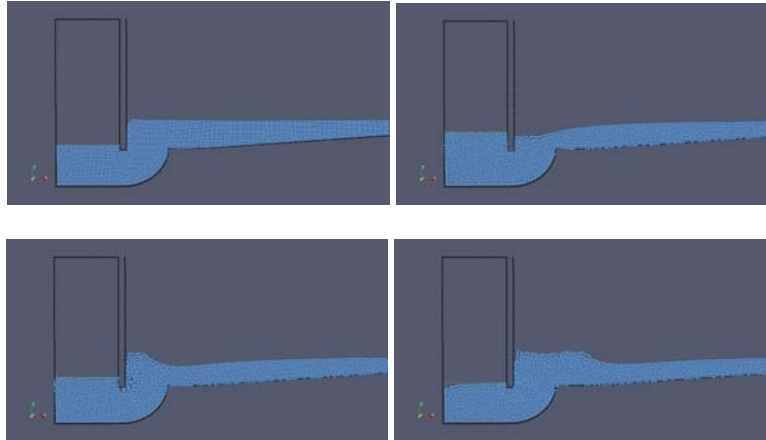


Figure 2: SPH wave generation

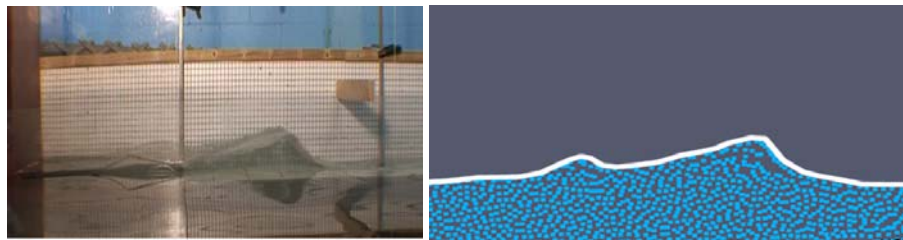


Figure 3: Physical model and numerical model free surface deformation

The whole energy added to the fluid system by the wave generator piston was not concentrated in a single wave crest. A secondary wave was always surging at the back of the first wave. Additionally, strong vortices were appearing above the wave generator slot, leaving a turbulent water surface after each wave generation.

## ***Wave shape formation***

Understanding of wave generation dynamic is presented here. We focused on three critical wave-maker dimensions: the slot width  $b$ , the local depth  $d$  and the piston width  $a$  (Figure 4). At  $t=T_w$ , semi-period of the wave-maker motion, going up, the free surface endures a small deformation which is assumed to be linear (**Hyp 1**: straight free surface deformation). The wave-maker piston amplitude is defined as  $Z_p$ . Since Hyp 1, the free surface motion is evaluated from a right angle triangle shape  $L \cdot Z_m$  (Figure 4).

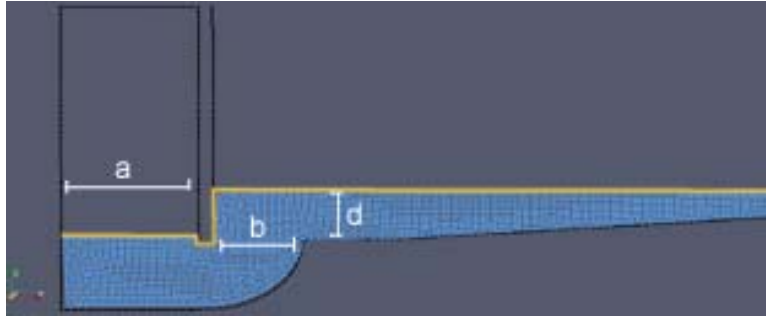


Figure 4: Free surface at t=0

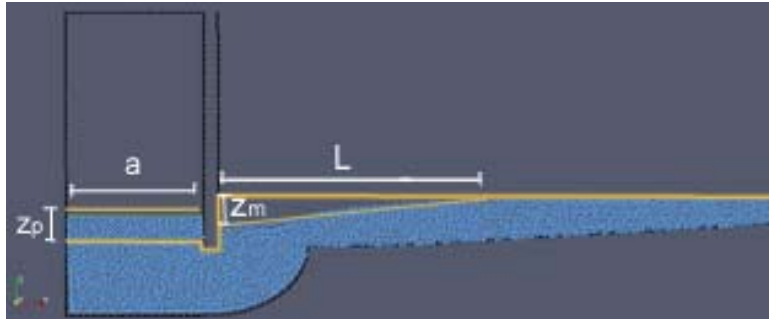


Figure 5: Free surface at t=Tw

According to the hypothesis of incompressibility, if  $W$  is the width of the pool, the equation (1) is introduced:

$$z_p \cdot a \cdot W = \frac{1}{2} z_m \cdot L \cdot W \quad (1)$$

And it comes:

$$z_m = 2 \frac{z_p \cdot a}{L} \quad (2)$$

The fluid displacement due to the wave-maker motion between  $t=0$  and  $t=Tw$ , is expressed by the flow  $Q$ :

$$Q = \frac{z_p \cdot a \cdot W}{Tw} \quad (3)$$

The free surface deformation calculated by the SPH model (Figure 6) shows a quasi-linear velocity profile, confirming *Hyp1*.

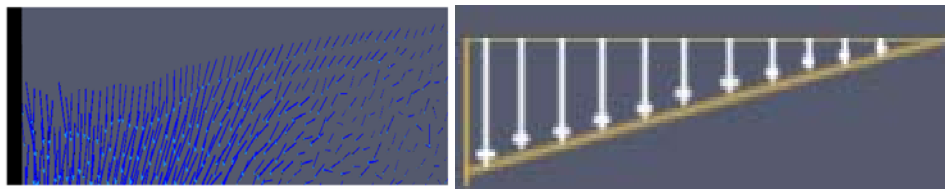


Figure 6: Free surface deformation simulated by the SPH model (left) leading to a linear velocity profile approximation (right)

Equation (4) defines the average velocity through the wave-maker slot:

$$U_{moy} = \frac{Q}{b \cdot W} \quad (4)$$

From integrating the velocity along the modified free surface area it comes:

$$U_{\text{moy}} \cdot L = \int_0^L U(x) dx \quad (5)$$

The velocity  $U(x)$  is basically defined as:

$$U(x) = \frac{\partial \eta}{\partial t}(x) \quad (6)$$

Where  $\eta$  is the surface level. As the wave propagates through shallow water, the motion is described by the wave equation (7), with  $C$  the wave speed:

$$\frac{\partial \eta}{\partial t} = C \frac{\partial \eta}{\partial x} \quad (7)$$

The wave speed  $C$  being by definition:

$$C = \sqrt{gd} \quad (8)$$

Combining equations (5) and (7):

$$U_{\text{moy}} \cdot L = C(\eta(L) - \eta(0)) \quad (9)$$

Since  $\eta(L) = 0$  and  $\eta(0) = -z_m$ , using (3), (4) and (9):

$$\frac{z_p \cdot a}{b \cdot Tw} L = C \cdot z_m \quad (10)$$

Finally, combining equations (2), and (10), two relations between the wave width, the wave elevation and the wave-maker parameters were found to be:

$$L = \sqrt{2b \cdot C \cdot Tw} \quad (11)$$

$$z_m = \frac{z_p \cdot a}{\sqrt{2b \cdot C \cdot Tw}} \quad (12)$$

These relations were confirmed by systematic study cases (Figure 7 and Figure 8) with the numerical model. The width of the wave generator slot is a critical parameter in terms of wave shape formation. A smaller slot basically tends to create a steeper wave (thinner and higher).

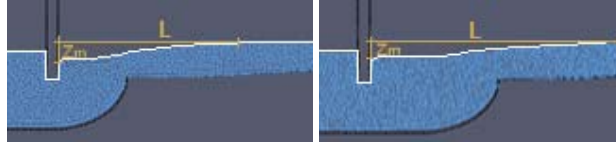


Figure 7: Free surface deformation simulated by the SPH model for two different wave generator slot width

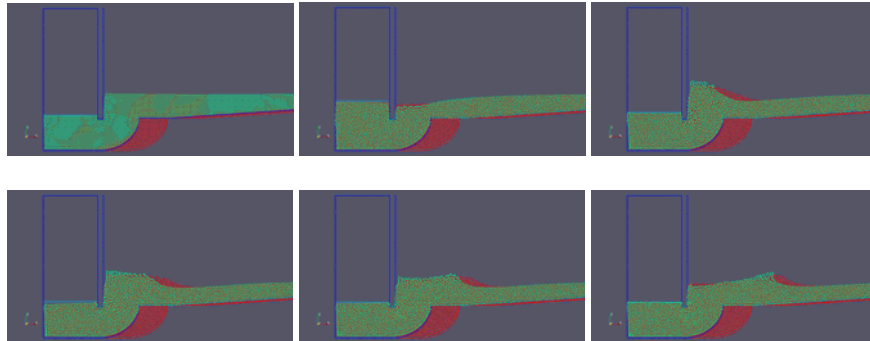
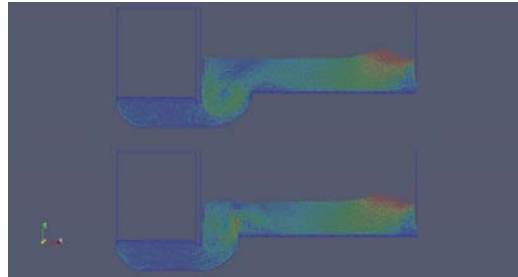


Figure 8: Free surface deformation simulated by the SPH model for two different wave generator slot width. The 'red' wave is created by a wave generator with a wider slot than for the 'green' wave.

## ***Vortex occurrence***

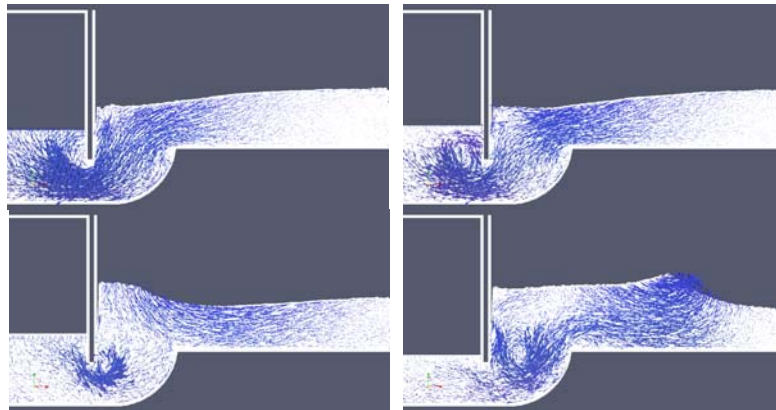
The initial wave generator design was creating a turbulent water surface after each wave generation. The bigger was the generated wave, the more important was the turbulence. The numerical model confirmed these observations. It appeared that a smaller wave generator slot was creating a more turbulent surface. A vortex is formed in the rounded shape of the wave-maker (Figure 9) and the energy dissipates slowly while the first wave is propagating in the tank, limiting the wave's quality after several wave generator motion periods.



*Figure 9: Vortices appearing in the wave generator rounded channel for different slot width design*

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Velocity profiles were analysed during the wave generation critical time steps (Figure 10). The conclusions were that the turbulences are likely to appear because of the sharpness of the separation wall inside the wave-maker and the thin vertical slot where the water flow accelerates due to the paddle motion. The wave generator rounded shape has to continuously keep the same width. The front wall has to be thicker with a rounded bottom wedge. These assumptions were verified with a set of different designs (Figure 11). A systematic comparison has been carried to select the ultimate design able to create several solid and clean wave faces in the pool.



*Figure 10: Velocity profile in the wave generator during a whole piston motion period*

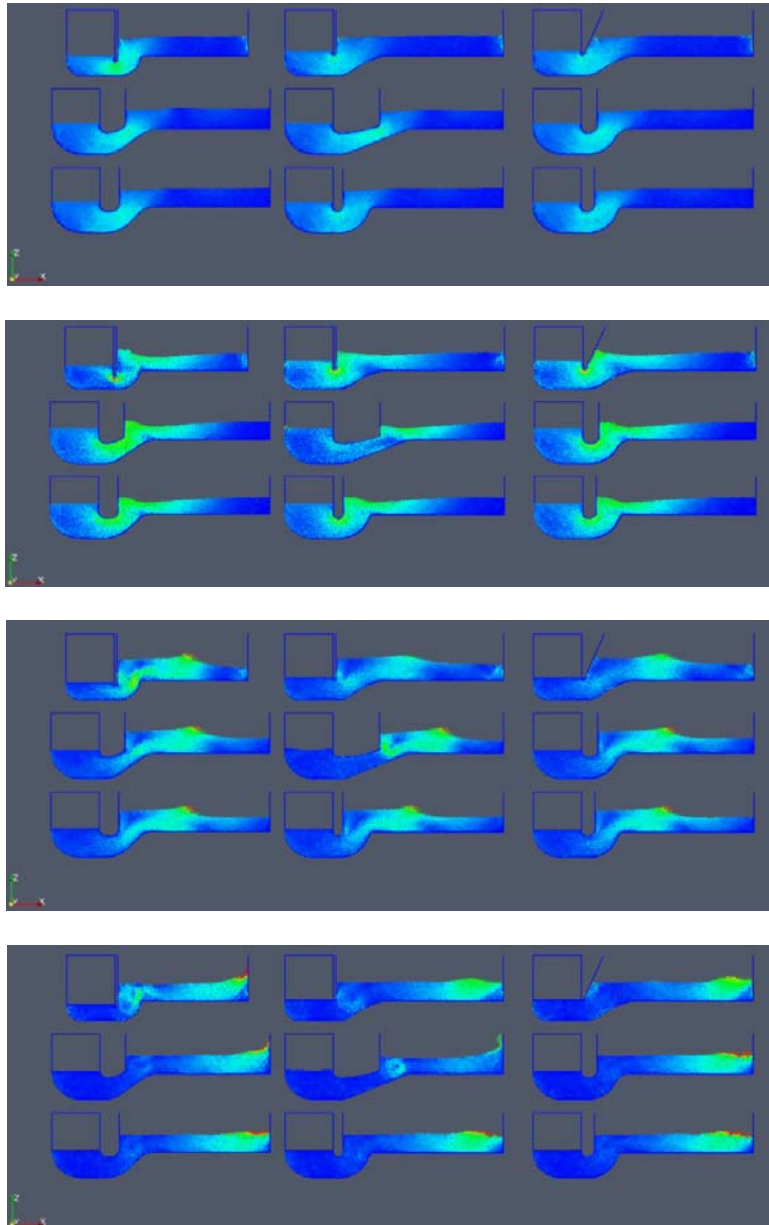


Figure 11: Wave generation simulation for several wave-maker proposed designs

## **References**

Dalrymple, R.A. and Rogers, B.D., (2007) "Numerical Modeling of Water Waves with the SPH Method," Coastal Engineering, 53/2-3, 141-147.

## **Acknowledgement**

SPHysics – SPH Free-Surface Flow Solver.  
 Open-Source Smoothed Particle Hydrodynamics code.  
[wiki.manchester.ac.uk/sphysics](http://wiki.manchester.ac.uk/sphysics)