Research into the Circular Wave Pool – a new method of generating controlled breaking waves

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Surfing as a sport is increasing in popularity worldwide. However, as it depends on being able to access wave conditions which are not always available, surfers have been trying to make indoor pools which recreate the surfing experience in a controlled manner. One of the more promising developments in this area is a circular wave pool, patented by Greg Webber in 2005 [9].

The original idea was to produce crystal clear perfect surfable waves in a large circular pool, breaking on an inner island. Although never designed to replace surfing, this phenomena would complement the surfing industry perfectly, opening up new markets and cementing old ones. Greg Webber and Steven Schmied took the idea to TU Delft and then to the Australian Maritime College for further research.

6 years later the research team has been analysing shapes, testing and predicting their wave-making performance in straight lines and finally producing perfect scaled waves in a circular test facility. This paper reports on this research and on how it has been used to further the design of the wave pool. Appropriate surfing speeds have been established from observations of real surfers. Scale model tests were used to determine the optimum Froude depth and length numbers. Finally a set of working beach locations and slopes have been estimated from the experimental study.

In addition to being able to be used to create perfect waves for surfing, the circular wave pool can also be used for a range of research activities, for example to generate controlled waves to investigate the loads generated by breaking waves on coastal structures and to investigate waves generated by manoeuvring vessels.

INTRODUCTION

Wave pool designs have progressed steadily in the last 80 years, however a commercially viable design still appears elusive [7]. In order to find the solution to the commercial difficulties of wave pool designs, a novel idea to produce continuous breaking waves has been patented by Liquid Time Pty Ltd [9], whereby one or more immersed bodies are rotated within an annular wave pool; see Figure 1 for the concept design. An immersed body here could be any object that disrupts the water surface, and most commonly this would be a ship hull, a submerged body (submarine), or even a wave dozer [4].

The inner ring of the annulus has a sloping bathymetry to induce wave breaking from the wake of the moving body, with the break point following the circular path around the island at a given depth proportional to the wave height. The aim is to be capable of creating waves suitable for surfers from beginner to expert level. As an added benefit, by
providing a safe learning environment, the overall surfing ability of the participants should be improved. The concept was proven, at least for a linear track, using a fishing vessel generating waves in a river estuary, where the vessel travelled in a straight line close to the bank. Figure 2 shows that one of the smaller moving-body (specifically a fishing vessel) generated waves can still be consistently surfed.

Figure 1 Proposed wave pool design by Webber Wave Pools and Liquid Time Pty Ltd. (reproduced with permission of Liquid Time Pty Ltd)

Figure 2 River testing such as that shown in this figure has proven that even the smallest of hull generated waves can be consistently surfed
The design space available to develop a wave pool is relatively large in comparison to waterborne vessel design. The main aim in designing a wave pool is to produce high quality surfable waves with the longest duration possible. The main constraint on the design is to produce the waves in the smallest space possible with a minimum amount of energy. In early linear tank testing of boat-like shapes it became apparent that increasing wave heights by simply increasing vessel beam meant that the limit of wave height creation due to a breaking bow wave was soon reached [8]. Also, from these early studies a clear advantage was seen in the use of “wavedozer” hulls which are essentially a flat plate driven at an angle of attack through the water. These wavedozer shapes form the basis of all work described within this paper. The initial wavedozer design is shown in Figure 3.

![Figure 3 The first wavedozer shape tested, direction of travel is from left to right](image)

**OPTIMUM SURFING SPEEDS**

As an initial approximation, the wave speed at the break point (the surfer’s path) was assumed to be approximately the same as the moving body speed \( V \). An initial aim of the project was to estimate such speeds by considering two questions:

1. What is the optimum speed for a surfing wave?
2. What is the minimum speed for a wave to be surfable?

Field observations of surfing waves were conducted at Lorne Point, Victoria [7]. Lorne point was chosen as the waves break parallel with the shoreline, and with a desirable shape at small (less than 1m) wave heights. Thus, Lorne Point is considered a close representation of waves desired for the final wave pool.

From observations at Lorne Point, the approximate minimum water depth was found to be 1m, giving a minimum wave speed of 3m/s, using the shallow water wave dispersion relationship given by Dean & Dalrymple [3]. This observation was supported by Dally [2] and Hutt *et al.* [5], who determined that the minimum mean wave speed was as low as 2.4m/s. The maximum water depth for Lorne Point was estimated at 3m, thus giving a maximum wave speed of 5.4m/s. Combining the observations of Dally and Hutt, a
maximum wave speed of 6.0m/s was obtained. Therefore the wave speed variation for
good surfing was estimated to lie between 3 to 6m/s.

Viewing the wave pool as a hydrodynamic optimisation problem, the first parameter has
been set. The absolute speed of the wave crests must lie in the range of 3 to 6m/s.
Considering then that the crest line will be between 60° to 90° to the line of travel, the
body creating the waves must travel at 3 to 12m/s, the upper limit being confined to expert
surfers only. For the purpose of this study a full scale speed of 6.8m/s has been used as the
base for further optimisation.

OPTIMUM FROUDE NUMBERS

There are two Froude number spatial scales that have a large influence on the size and
slope of waves produced by an immersed body. The first scale of interest is the length of
the body and the second is the water depth. Considering that the velocity of the body has
been set, as per the previous section, these two spatial scales can be used to create the
length and depth based Froude numbers for optimum creation of surfable waves.

The length based Froude number to create the largest waves possible has been well
documented to lie between 0.45 to 0.5 ([6], [1]). If the absolute value of the speed has
been set by desired surfer speeds, then setting the length Froude number has the effect of
prescribing the length scale of the body. It then remains to determine what the length scale
of the body actually is.

For thin ship forms determining the length scale of the hull is relatively easy, being the
waterline length, however for the shapes considered here (a wavedozer) this estimation is
quite difficult. For example, a study was conducted whereby the angle of attack of the
wavedozer was varied whilst maintaining aft corner depth, thus altering its waterline length
considerably. Although potential flow numerical results predicted a large variation in
wave heights as a function of angle of attack, the experimental results shown in Figure 4
failed to discern a logical pattern with respect to Froude length number variation for these
bodies varied in this way. The result presented in this figure are for wave height
normalised by water depth ($H^*$) as a function of model scale speed ($V$). The experiments
were conducted at a model scale of 1:20 in a model scale water depth of 250 mm, wavedozer immersion was 50 mm and the wave heights were measured at a distance of 375 mm
from the sailing line in a pool of diameter of 5 m. At this point none of the waves were
fully breaking, all of the waves were steady and the highest Froude depth number was
0.99, thus the wave patterns retained a familiar Kelvin wave pattern in plan view. This is
certainly the subject of further investigation.

Due to the non-dispersive nature of shallow water waves, wave heights at a Froude depth
number of 1.0 are much larger than at lower speeds. That is, the energy is concentrated in
fewer waves at this Froude depth number, thus making larger wave heights. In this critical
region a soliton may be pushed forward from the vessel, such as that depicted in the image
series of Figure 5. These waves can be large in height (although they have no preceding
trough), but they are also unstable and likely impossible to surf. Therefore, an aim is to set
the surfing pool design with operation just below a Froude depth number of 1.0, without
actually producing such disastrous solitons.

With the speed set from surfing data, the length of the wavedozer and depth of water set
from experiments, the major parameters of the wave pool have largely been determined.
Figure 4: Variation in wave height (difference between trough and crest) normalised by water depth as a function of velocity for changes in wave dozer angle of attack. Wave dozers are all variations of the geometry shown in Figure 3.

Figure 5: Series of images (starting top left, finishing bottom right), showing the development of a large soliton from a wide body at a critical Froude depth number. The carriage began to slow after the fourth frame and was completely stopped before the final frame shown. The final picture is obscured because the large wave completed swamped the camera, even though the camera at this height had never been wet for all runs at lower speeds. Model used was a parabolic Wigley hull with a length to beam ratio of 1.17 in a water depth of 500 mm in a 3.55 m wide towing tank.
OPTIMUM BEACH LOCATION

The location and bathymetry of the beach is still being examined in detail. However, as the exact break point of a surfable wave is controlled by shoaling bathymetry, it is clear that the bathymetry for breaking waves needs to coincide with the wave train from the body, producing a maximum wave height which is stable in space and time. To achieve this, a location has been selected outside of the near field, such that the wave pattern is not dominated by the local effects around the moving body, indicated by a constant wave height with respect to transverse distance.

For the purpose of finding the best location for initiating wave breaking by tailoring the beach bathymetry, experiments were performed on a circular track model with no internal beach at a diameter of 10m. The test conditions were set by the speed and Froude number limits discussed above. The resulting measured wave height variation with distance from line of travel normalized by the track radius is shown in Figure 6. In this figure changes of lateral distance of between 0.125 and 0.225 times the radius can be seen to have a small change in wave height. Therefore, it is proposed that the best location for the beach will be in this area, as changes in wave height could be controlled solely by changes in bathymetry, permitting the creation of the best surfing wave.

![Figure 6 Variation in wave height normalised by water depth with distance from body line of travel for the 14° angle of attack wave dozer. Scale was 1:20, transom depth of 50 mm, measurement distance of 375 mm from line of travel for a 5 m radius pool.](image)

CONCLUDING REMARKS

The design of a circular wave pool concept has been produced by Webber Wave Pools and patented within Australia and Internationally. This design shows great promise to not only produce a unique facility for expanding the surfing industry but also to conduct significant research into repeatable breaking waves.
The optimisation of the surfing wave pool begins with the desired full scale speed required for surfing. This is due to the small window placed on practical surfing speeds. Depth and length Froude numbers for the moving body which generates the waves can then be controlled for optimum wave creation. The design process then proceeds by maximising wave height whilst maintaining a non-breaking wave at a distance from the travel line of the pressure source. The wave used for surfing can then be formed by altering the bathymetry at the correct location.

Although there is still significant research and design work to be completed, the last three years have yielded some extremely valuable quantitative results. The promise of making the perfect repeatable-surfable wave seems to be coming true.

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