ROBOW: A wavemaker for use in water of infinite depth

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1. Introduction. In 1989 the need arose to study breaking, deep-water surface waves under carefully controlled conditions. The wavemaker was to have no underwater moving parts. We shall describe a model designed with these requirements in mind.

The basic idea was as follows. A long, flat-bottomed barge has two independent wave-making motions in two dimensions: heaving and rolling. If the barge can be made to execute these in such a way that the two kinds of waves produced are in a certain phase-relation then on one side of the barge the waves may be cancelled out, and on the other side the wave energy will all be propagated away from the barge.

Intuitively one might expect that the type of motion most likely to produce such an effect would be a rocking motion, in which rolling and heaving displacements were 90^{o} out-of-phase, as in the motion of a flat, narrow plate floating on the water surface.

To produce such a motion one might cause a heavy, lead cylinder, for example a pipe filled with lead shot, to rotate about a horizontal axis fixed relative to the deck of the barge, as in Figure 1.

2. Realisation. An enameled metal oven tray, of internal length 39.9 cm and width 27.7 cm, was trimmed by removing its external flanges. Wooden strips fastened to the sides of the tray provided additional free-board, so that the external dimensions of the "barge" were 43.2 cm x 30.0 cm x 6.5 cm.

Independently a "rocker" was constructed from Meccano parts as in Figure 1. A hollow iron pipe of diameter 2.7 cm and length 9.4 cm was filled with lead shot and mounted on an arm of length l = 6.35 cm (2.5 in) the pivot being at a height h = 8.3 cm above a wooden base of thickness 2.3 cm. The total mass m of the cylinder was 238 g. Its weight was counterbalanced by a light spring.

The arm was rotated by a 6V/1000 Meccano motor via a 6:1 gear train. The motor itself contained a gear box with six possible speed reductions, ranging from 1:3 to 1:60. To avoid pitching, the weight of the motor (140 g) was counterbalanced by a small steel plate. The motor was controlled by a standard transformer and rheostat, operating on the mains voltage (110V A/C).

The "rocker" was placed on the deck of the barge and wedged in place. The total weight (displacement) of the barge and rocker was 1473 g.

3. Preliminary tests. The wavemaker was first tested, successfully, in a household bath on 25 December 1988. Soon afterwards, tests were carried out in the 20 m wave channel in the Department of Applied Mathematics and Theoretical Physics in Silver Street, Cambridge, with periods of oscillation ranging from 0.45 s to 0.70 s (wavelengths λ from 32 cm to 76 cm). However, the width of the channel being only 61 cm, reflection from the channel walls produced trapped oscillations, making the waves non-uniform in height across the channel. Hence it was necessary to use a wider basin.

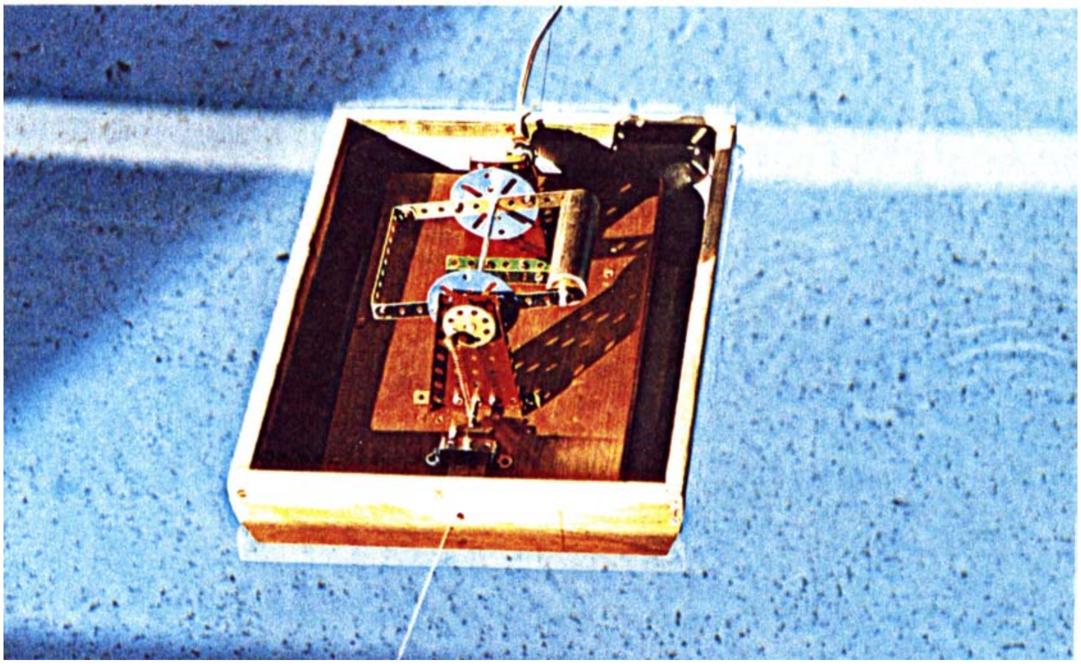

Figure 1. A close-up view of the model ROBOW.

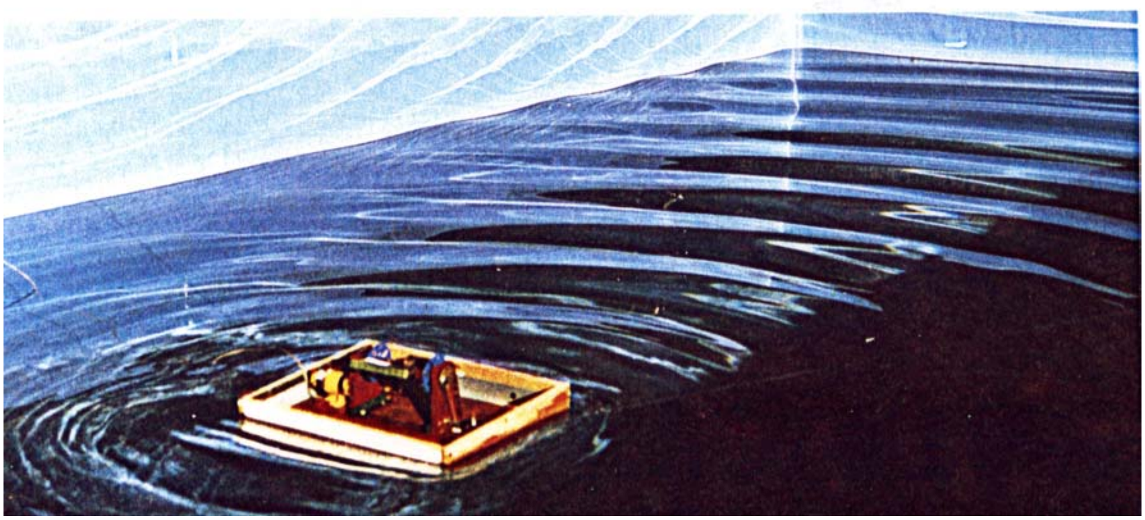

Figure 2. The ROBOW in action in a small swimming-pool.

On 3 January 1989 tests were carried out in a small swimming-pool 6.94 m x 3.46 m x 97 cm, at Spitzweg Strasse 25c, 8012 Ottobrunn, W. Germany, with the kind permission of Dr. Ernst R. Wittermann and Frau Wittermann. The wavemaker was attached loosely by a cotton thread to stakes on either side of the pool. Figure 2 shows the appearance of the pool after the wavemaker had run for 30 s. The wavemaker tended to move up-wave under the force from the radiation stress of the waves, but the cotton thread prevented it from moving too far.

To measure the waves, a rule was inserted vertically into the water, at points along the centre line. All measurements were made after the elapse of several wave periods, but before the main wave front, travelling with the group velocity, had time to be reflected from the far wall of the pool. In Figure 2 the wave period was 0.455 s and the wavelength 30.9 cm. The distance x between the wavemaker and the measuring point was 80 cm, or about three wavelengths. The measured wave amplitude (half the crest-to-trough height) was 1.0 cm, giving a wave steepness $s = 2a/\lambda = 0.065$ compared with a theoretical maximum 0.141.

The wavemaker was named ROBOW, for "Rocking-Boat Wavemaker."

4. Instrumented tests. Early in 1989 calibration of ROBOW was carried out in the Hydraulics Laboratory of the Scripps Institution of Oceanography, La Jolla, California. The wave basin has dimensions 15 m x 18 m, with a sloping plane beach along the longer side. The depth of water was 67 cm.

Wire wave gauges recorded the surface elevation at seven points as follows. Points nos. 2, 3 and 4 were on the center line, at x = 36, 46 and 26; points nos. 1, 6, 7 and 8 at x = 36, y = -40, 20, -20 and 40 respectively, the units being cm. The wave frequency lay in the range 1.23 to 3.99 Hz. At each frequency the waves settled to a practically steady state.

In these experiments the dimensions of the wavemaker were as described above, except that the rotating mass was increased to 298 g, and to avoid nonlinearity the arm length l was reduced to 2.0 in.

Figure 3 shows typical results for the local wave amplitude a. The highest amplitude, a = 0.80 cm, was recorded at point no. 4 at a distance of 26 cm from the wavemaker

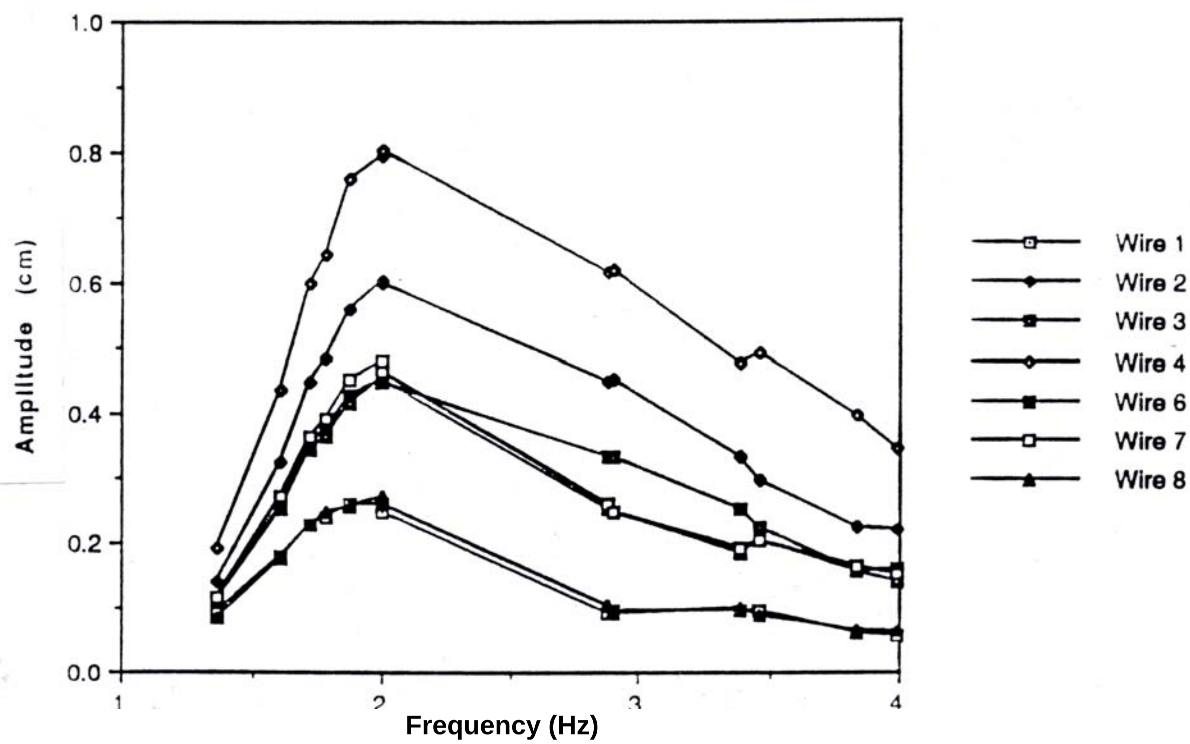

Figure 3. The measured wave amplitude a as a function of the peak observed frequency f, at stations nos. 1 to 4 and 6 to 8.

The effect of increasing *l* to 2.5 in while keeping *m* constant was to increase slightly the wave amplitude on the low-frequency side of the peak, without affecting the maximum amplitude or slope.

5. Discussion. The maximum steepness achieved by ROBOW at a steady frequency was about half the steepness 0.141 of a limiting Stokes wave. Further experiments using the method of wave focusing (Longuet-Higgins 1974) produced comparable results. It should be noted, however, that for wavelengths λ less than 1m gravity waves are subject to strong damping by parasitic capillaries (Longuet-Higgins 1963, 1995); these could be clearly seen on the forward face of the gravity waves in the present tests.

The theoretical amplitude of the waves generated by a long ROBOW at low wave steepnesses is an interesting theoretical problem which might be attacked by known techniques (Ursell 1949, 1970, 1954, 1964). This is a challenge to the present audience.

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Discusser - D.V. Evans:

A good way of constructing a good, unidirectional wavemaker is to mount a circular cylinder on an eccentric axis and rotate it in a narrow wave tank. This is because Ogilvie (JFM 1963) showed that waves only in one direction are generated down the tank. This idea formed the basis for the Bristol Cylinder wave energy device which I was involved with some years ago. (See for example Appl. Ocean Research 1979 Vol 1.)

Reply:

Thank you. I was indeed aware of the unidirectional wave-making properties of the horizontal circular cylinder. However, if the axis of rotation is supported rigidly, the device contravenes the requirement that there be no underwater moving parts. If on the other hand the cylinder is tethered by underwater cables, as in one version of the Bristol Cylinder, then the cables must be attached firmly to the bottom. In very deep water this is impracticable.

One could produce the rotary movement about a fixed axis by the action of a heavy weight made to rotate eccentrically about the axis of the cylinder, and inside it. But the mean depth of the whole device would still have to be kept constant. Perhaps this could be done by attaching the two ends of the cylinder to buoys at the water surface by elastic cables.

Altogether, the rocking barge seems to be a simpler solution.