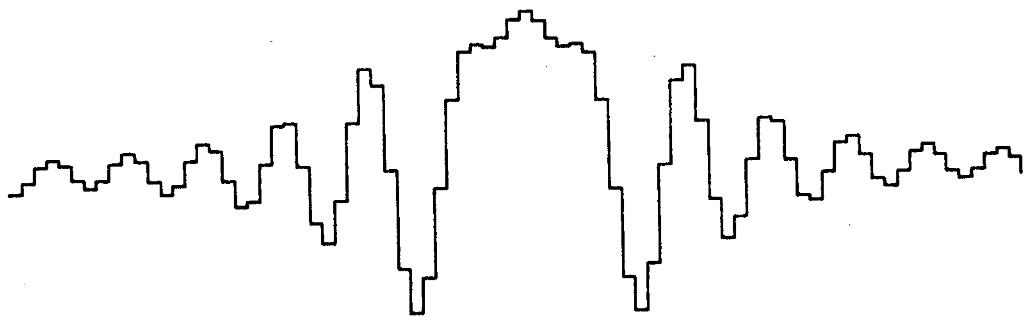
Edinburgh Wave Power Project

Fourth Year Report
Volume 3 of 3



July 1978

CONTENTS

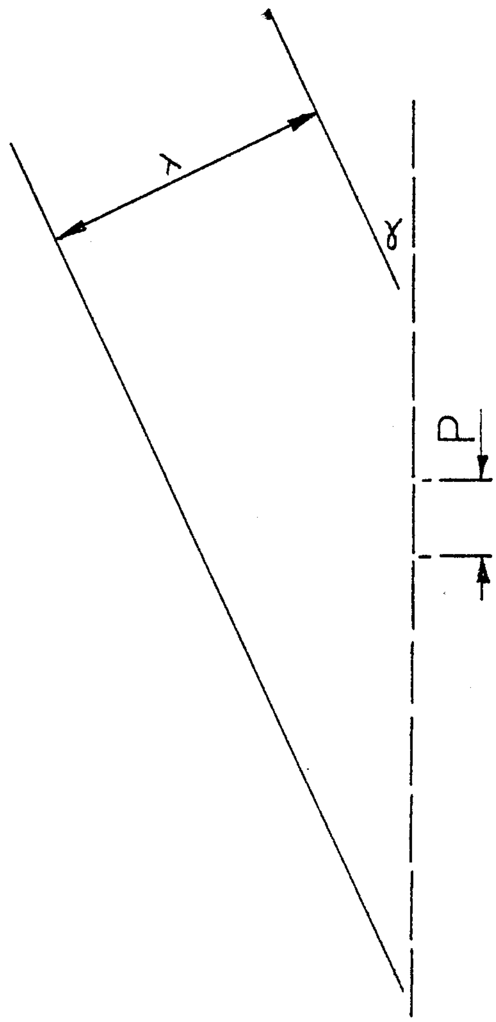
BUILDING THE WIDE TANK

Our aim was to construct a tank with complete control of directional distribution of energy as well as spectral shape. This control is important for several types of wave power device but it is of critical importance for the design of the backbone of a duck string.

WAVE FRONT GEOMETRY

The mixed sea tank at HRS Wallingford consists of a group of 10 wavemakers arranged in a crescent. They send waves towards a central area. Conditions are well defined over a two metre central square. While this was excellent for work on oil rigs, it looked as though a duck string would need a much wider front of controlled sea. We decided to examine the possibility of using a straight line of wavemakers. We reasoned that, by controlling the phase difference between the signals sent to adjacent wavemakers, it should be possible to generate wavefronts at an angle to the line of wavemakers. The analogy with Huygen's principle in optics may be helpful.

$$\sin \alpha = \frac{\phi \lambda}{2\pi P}$$



We discussed the problem with the Department of Civil Engineering at Heriot-Watt University, who had been generous to us with time in narrow tank tests, and who were planning a mixed sea tank at their new laboratory at Riccarton. They agreed to try the idea. We built an orchestration unit based on an Intersil micro-processor which could produce the signals for 20 wavemakers. This was tested successfully in April 1977. It was very clear that diagonal fronts could be produced.

SIZE

The choice of model scale of 1:150 was easy but the decision about the size of tank to build was particularly difficult to make. We believed that the central part of an infinitely long backbone should have lower bending moments than those in one which spanned a single wave crest. But how wide was infinity? It was clear that a plan to use a lecture theatre would leave us short of width. The final choice was based on the estimate of nine crest lengths, the amount of money available and the size of the site. These all converged towards a tank with outer dimensions of 27.5 x 11 m. Temporary planning permission was given on the understanding that demolition could be demanded in 1982. It was important to ensure that the tank could easily be moved.

WALLS

We chose to build the tank walls from precast concrete units known as "Belcons", available from Messrs. Bell & Webster of Essex Road, Hoddesdon, Herts. These are L-shaped modules available in a range of heights with a variety of corner designs. Their own weight, aided by the weight of liquid on the toe of the L, allows them to contain fluids with specific gravity up to 1.6. We chose a width of 3' and a height of 5' which would allow a freeboard of about 300 mm above a water depth of 1.2 m. Bell & Webster charge £21 each (1977) and can make reduced shape specials by adding inserts to the mould for 50% extra. A generous margin must be left for the labour of placing them in position.

The weight of a Belcon unit would probably stop it sliding but we bedded them on to mortar and drilled holes for steel pins into the concrete base. The laying cannot be exact and the pitch gained about 6 mm per module.

A waterproof lining of a polyurethane-backed felt was installed by Messrs. Edmund Nuttall's Insituform Division, Unit 6, Roundwood Industrial Estate, Ossett, West Yorkshire. It seemed that this could easily be punctured by falling objects, but we find that the water serves as a valuable protection. Two early leaks were found (using an electrical potentiometric method) and sealed. Since then no further leaks have occurred despite some spectacular falling objects.

It might have been possible to seal floor cracks and gaps between the Belcon units with a suitable preparation and dispense with the plastic lining but the amount of outward deflection caused by water pressure suggests that extra corner brackets would have been desirable for this method of sealing. Plastic linings provide the valuable feature of complete separation between water and concrete which helps with corrosion problems.

Belcon units are an attractive alternative to Braithwaite panels because you only pay for the perimeter rather than the area of your tank. If holes are needed, the use of a Hilti impact drill is strongly recommended.

ABSORPTION

Most wavemakers are controlled by signals which fix their displacements. They behave as rigid reflectors. We were convinced that wave power research demands wavemakers capable of acting as beaches, absorbing incident waves. To do this, the wavemaker needs an input which controls the force signal applied by the flap to the water, and a transducer to measure the velocity of the flap. The velocity voltage is amplified and fed to the force input. This gives a force proportional to velocity which is the requirement for absorbing energy. An external signal added in to the same input makes waves without affecting the absorption.

DISPLACER

Any design of wavemaker can be fitted with absorbing features but force control will be easier and power consumption halved if the displacer does not move water to the rear. This points to ducks, sliding wedges or flap/membrane combinations It is much easier to make the rotating location for flaps and ducks than the sliding one for wedges. The curved surfaces of ducks are harder to make than the flat surfaces for flaps. We used a flap made in the shape of an isosceles prism, hinged at its apex. It was made from four triangular plates with folded edges which were riveted between rectangular front and back plates. We used 18 SWG HS 30 light alloy. Anodising has so far prevented corrosion. We have previously mentioned problems with aluminium and concrete. If tank water has to be in contact with concrete, it may be that GRP flaps would be more suitable. The design must combine low inertia with rigidity.

MEMBRANE

The single-sidedness so desirable for making absorbing wavemakers can be achieved by using flaps to support a waterproof membrane. We chose a woven nylon fabric with a polyurethane backing. The thickness is 0.2 mm. It is made by Carrington Viyella (GDD), 183 Thornton Road, Bradford, BD1 2JR. It is necessary to cut the fabric and glue in triangular gussets at the pitch of the wavemakers.

The gussets form a rolling seal between adjacent wavemakers. We are indebted to Eric Wood for the glueing technique. Polyurethane is soluble in tetrahydrofuran, commonly known as THF. A small amount brushed on makes the film behave like an adhesive tape for about 45 seconds. The fabric can only be glued polyurethane to polyurethane.

The strength of the Carrington fabric is remarkable. We would have used a lighter one if it had been available and would have no hesitation about using .02 mm at a larger scale. It is, however, important that the ends of the gussets and the hinge line of the flaps should coincide. This can be achieved by using the fabric itself as the hinge.

FLAP SIZE

The most critical decision in wavemaker design is concerned with the depth of immersion of the flap. There is a direct conflict between the generation of large waves at low frequencies and the absorption of reflections at high frequencies. Flaps run out of displacement at the bottom end of the spectrum and have too much added hydrodynamic inertia at the top. Distortion occurs with large angles of movement and cross waves break out if there is too much displacement too low in the water. We decided to go for optimum performance at 1 Hz and finally chose a hinge depth of .5 m and angular movements of $\pm 15^{\circ}$. Forces, velocities, drive power and wave height were then immediately defined. Gilbert, Thompson and Brewer[(1)] have written an invaluable paper on wavemaker design. Their curves allow for the prediction of angles, phase and forces, as a function of wave height and period. We regard this information as essential for the production of an economical system.

The width of the flap is a compromise between the need to generate and absorb high frequencies at large front angle and the restrictions on the number of parts to make. We wanted to use Dexion for the wavemaker supports and this is supplied with holes on a 1.5" module. We chosen 12" for the wavemaker pitch and left a clearance between units of .7". We would advise wealthy tank builders to consider something even narrower.

DRIVE

The next critical decision is the choice of motor. Our previous experience with printed armature motors had been satisfactory. These have a very low inertia and give a torque which is proportional to current minus a roughly constant amount to overcome static friction.

If we were to use the input to a current amplifier driving the motor as the force input, we would have a system that would respond badly to low level input signals because of this error. This would give us poor absorption and impure wave generation. To overcome this problem we use a force feedback system, which reduces these errors by about 95%. Force is sensed by a transducer mounted on the flap. The force voltage is compared with the input voltage and any difference is fed to the power amplifier driving the motor. This changes the force voltage until the difference is zero. With infinite gain in this loop, one can see that the force is constrained so that it always equals the input. In practice we have achieved a gain of about 20 before the onset of instability.

Printed armature motors are produced in the UK by Printed Motors Ltd., (Aldershot, Hants.) but the company is notorious for poor delivery. We found a supply of scrapped G12M motors which had previously been used in computer disc drives. The new price for a G12M is about £100 but Electronic Brokers Ltd. of 49/53 Pancras Road, London SW1 2QB were charging prices from £25 for an unused unit down to £2 for severely damaged ones. We bought 120 from which about 100 have been rebuilt. The most common fault was the failure of the bond between the printed armature and the spindle. Our repair technique may be of interest.

A motor cannot be opened by pulling its end plates apart because its magnets are too strong. But if a bar is screwed to one plate and rotated 45° about the motor axis, then opposite magnetic poles will force the motor to open itself. Armatures can be reglued easily. We found high temperature Araldite resin from CIBA very satisfactory.

Unfortunately, opening the motor to reglue the armature destroys a large part of the magnetic field. If the motor is reassembled its torque will be about one fifth of normal. Labels on the motor faces warn that disassembly makes the guarantee void. If these labels are removed, two electrical terminals will be found. They are connected with a wire coiled round each of the magnets which may be used to remagnetise them. We found that several pulses of 7,000 amps were effective. This may be obtained by the discharge of low impedance paper capacitors. We used 1,000 μF charged to 1,000 volts. An old-fashioned knife switch flicked by hand produced a splendid flash. It was necessary to catch the back EMF with a diode. The voltage and current ratings must be carefully chosen. We used two International Rectifier 45LR100 diodes in parallel. The electrical connections must be kept very short and flat. We used 3" wide strips of 16 SWG NS4 aluminium. The easiest way to confirm that a satisfactory magnetic field has been made is by measurement of the output voltage generated when the motor is driven by gripping its spindle in the chuck of a bench drill.

DRIVE WIRES

The connection between motor and flap must have no friction or lost motion. It is clear that the maximum backward drive force can never exceed the outward hydrostatic force of the water. If it did, the water would be left behind. This means that a wire can be used for a pull-only drive.

We can wrap a wire into a screw thread cut into a pulley mounted directly on to the motor spindle. The choice of wire and pulley diameter demands some careful thought. When a wire is wrapped around a cylinder, each strand is repeatedly bent. The strain depends on the ratio of wire strand diameter to pulley diameter. Small pulley diameters give a large step-down between motor and flap and so let the motors approach the high speeds necessary for efficiency but they induce high levels of fatigue in the drive wires. We chose a wire made from 7 x 7 strands with a total outside diameter of 1.5 mm. When wrapped around a 40 mm pulley, this will suffer about 4,000 micro strain which is well into the fatigue area. We judge that wire replacement is better than an intermediate gear box. The wire used in the narrow tank shows no sign of fatigue after 9 months. About half the wires in the wide tank show signs of trouble after 6 months. This may have been caused by a traumatic incident early in their life before a safety box protected the wavemakers from overdrive. We continue to experiment with wire types but there is plenty of warning before breaking occurs and, as replacement of wires takes only a few minutes per wavemaker, we reckon it a small price to pay for such a cheap drive.

It is interesting to note that wire drives get more suitable as scale rises because the same fine strands can be used in 7 x 19 cables on bigger pulleys. The screw thread in the pulley is cut with a tool tip radius matched to the wire diameter. We found that two turns of wire would creep round the pulley by about one thread per week, but that five turns show no sign of creep.

SPRINGS

Single-sided flaps need some form of spring to balance the substantial hydrostatic forces. The rate of this spring can be chosen to cause a resonance at the most useful frequency.

We found that a rich variety of spring rates can be assembled from combinations of chest expander springs made by Herbert Terry & Sons Ltd., (Millsbro Road, Redditch B98 7BU). For larger wavemakers, it may prove sensible to generate a large capacity zero rate spring with a vacuum cylinder and then add a small amount of positive spring directly.

FORCE SENSING

The force-sensing transducer should be as close to the water and as rigid as possible. We decided to use a pair of piezo electric discs in a sandwich with a central shim electrode. Piezo electric devices are well suited to charge amplifiers made with modern low-offset current FET operational amplifiers. Their sensitivity versus rigidity performance is probably better than any resistive film strain gauge element and they do not need a stable supply for excitation. But they cannot provide any zero frequency stability and this may cause some problems with very low frequency oscillations. A variety of piezo electric crystals are available from Vernitron Ltd., Thornhill, Southampton, SO9 5QF.

VELOCITY SENSING

The coupling between motor and tachogenerator is a possible source of resonance and so must be very rigid. Our G12M motors have double-ended spindles. We used the rear spindle to drive a tachogenerator and joined the two with collet tube and pinch blocks.

Delivery problems forced us to change from a purpose-built tachogenerator to a component designed for use as a motor. There is very little difference in the design of the two, the main one being a larger spread of output voltage against shaft speed. We used Trident MAXON S 2325.921, calibrated each unit and calculated a resistor value for the conditioning circuitry to correct the small variations. These motors cost £8 each and have proved satisfactory. One small problem may be of interest; the skew winding of the cup armature will give an output from an axial shaft movement. An elusive oscillation was traced to this effect.

POWER

The laws of conservation of energy have to be observed by wavemakers. Designs which use single-sided flaps and correctly chosen spring rates will look like resistive loads from the point of view of the motor drive. They will be very efficient and the power requirements can be easily calculated from the size of the waves generated. Long crested breaking waves at 1 Hz and converging peaks .5 m high can be generated by power amplifiers using only two power transistors. We feel that very many wavemakers are grossly over-powered and that electronic drive should be feasible in a 1/10th scale tank. But it is important to avoid heavy, inertia-dominated displacers and to get the spring rate correct.

BEACHES

Natural beaches make waves break when they come into water depth about the same as their own height. The angles which give low reflections are so nearly horizontal that large areas of building space would be wasted if simple slopes were used in wave tanks. Most of the dissipation is caused by breaking rather than by rubbing on the bottom and so the first part of the slope is just used for the change from deep to shallow water and does not help to dissipate energy.

We have been experimenting for some time with beaches made from vertical sheets of 'Expamet'. A pattern of slits is cut into a thin sheet which is then pulled out and corrugated. The result is lots of sharp corners and no volume. We use a grade known as 'Filtafoil' Type 451A (003" thick with .055" strand). It is available in 1.83 m x .91 sheets at 60 p per square metre (1978) from Expamet Industrial Products Ltd., P.O. Box 14, Stranton Works, Hartlepool, Cleveland TS25 1PR.

Our first beach designs for the narrow tank consisted of loose sheets packed with some attempt at higher density to the rear. But for the wide tank we now feel that it is better to pack the material into triangular wedge-shaped cages arranged side-by-side. The cages are made of folded sheets of weldmesh which are hot-dip galvanized after cutting and folding. We argued that the progressive increase in density 'would not let the waves know which bit to reflect from'.

We hoped that reflection coefficients would be independent of amplitude but this is not the case. The beaches show very much the same relationship of reflection to wave steepness as other designs. With 2,000 sheets along the tank, performance was disappointing. But a further 1,000 sheets packed tightly at the rear of the wedges gives satisfactory results except at very low wave amplitude. It may be that the best possible design would use expamet wedges in front of active absorbers. The latter are probably the best way to get rid of small amplitude waves.

This beach design is not cheap. The cost, including cages, is about £5,000, one-sixth of the cost of the whole tank.

WORK PLATFORMS

Groups of four beach wedges lie inside frames made from vertical scaffold poles and 90 x 50 mm rectangular horizontals. They were galvanized after welding. They are joined by scaffold tubing. We sprayed the scaffolding connectors with a cold zinc aerosol and no corrosion has occurred.

Work platforms, made from 22 mm phenolic glue chipboard, lie across the frames. They are reinforced by Dexion channel and painted with Marine deck paint containing an abrasive. A narrower work platform is provided in front of the wavemakers. The wavemaker motors and electronic control boards are all mounted on a Dexion frame which hangs down from the roof and is tied to the back Belcon units. Dexion is an expensive way to buy steel but a cheap way to buy paint and holes. We find that the channel section is the most useful.

SIGNAL DISTRIBUTION

If you take a wire layout for a single wavemaker and multiply everything by 89, you end up with a spaghetti fight. We put a good deal of effort into the design of a signal multiplexing system. Commands for all the wavemakers are carried on one common wire which is part of a 25-way ribbon cable. It is joined to control boards at each wavemaker by insulation-piercing connectors so that there is an unbroken path along the length of the tank. De-multiplexing circuitry is built into each control board and operated by a D type flip-flop acting as part of a long shift register. The multiplexing switches come in a package containing four. We used the spare three to send back to the control desk information about the forces, velocities and positions of each wavemaker. These have proved very useful for commissioning because an ordinary oscilloscope can display the information in a 'God's eye view' spatial form. We may be able to use this force and velocity information to measure power sent out and power reflected. Other wires in the 25-way ribbon are used for clocking the shift register, distributing and checking low level power supplies and recording any overload conditions.

The high current supplies are sent along the tank on three bus-bars made from 20 mm square light alloy. They are joined by fish plates and 8 mm bolts and have 6 mm holes tapped at the pitch of the wavemakers. They are insulated by a polythene pipe which is pierced by the 6 mm screws taking power to each amplifier.

The high current display can provide 500 amps and $\pm$ 30 volts. It operates from a three-phase input and was specially built by Douglas Electronic Industries, Louth, Lincolnshire. The power amplifiers were designed to reject power supply ripple and no reservoir capacitors were provided.

KEY POINTS FOR TANK BUILDERS

The paper by Gilbert, Thompson and Brewer is essential. It is very important to achieve the lowest possible friction in the wavemaker movement. The more that there is then the higher must be the loop gain of the feedback network, the harder it will be to achieve stability and the worse will be the quality of the waveform. While the text books of dynamicists are full of simple mass spring systems with one natural frequency, any practical object can find hundreds of ways to oscillate. It is essential to measure and understand the frequency response of your system.

The displacer and its force sensor must be rigid but light so that resonances are pushed to high frequencies. With our design the dominant resonance in the wavemaker drive was at 60 Hz.

It is important to have free access to as large an area of tank as possible. Work platforms and glass sides should make it as easy as possible to see and get near the waves.

WIDE TANK USERS' GUIDE

AIM

The Edinburgh Wide Tank was constructed specifically for wave power work. The aim was to be able to test a 150th scale model of a duck-based power station. The tests would cover both averaged-sized seas and extreme storm conditions typical of the North Atlantic.

PHYSICAL DETAILS (See Figure 1)

We do not know how long a spine will be needed to give ducks a suitable reference to react against but we believe that a tank width of 25 m should cover all possibilities. The useful length of the tank is 7.3 m and the water depth is 1.2 m. This gives a full scale depth of 180 m which can be considered "deep" for all but the very longest waves. ("Deep" water is water whose depth is equal to or greater than half a wave-length.)

The waves are generated by a bank of 89 wavemakers along the west end of the tank. Each wavemaker is .3 m wide and has the capability of absorbing incident waves. Beaches composed of expanded aluminium held in galvanized steel cages are placed along the east and south sides of the tank, while at the north end, a view inside is provided by a glass window 9.1 m wide extending .25 m below the water surface. This is where all the control and instrumentation equipment sits and space is available for storage, model preparation, etc.

Access to the tank is normally via a passage to the James Clerk Maxwell Building at the north end, but a large roller blind entrance at the NW allows lorries to unload inside. There are two walkways running the width of the tank; the one at the west end is placed over the beaches and is 2 m wide, while the other is much narrower and is mainly intended as a maintenance gallery for the wavemaker electronics. Two half-ton cranes will soon be available. They are placed at the 1/4 and 3/4 width points and can travel the length of the tank using rails in the roof. The work area at the north of the tank is lit by skylights but the rest of the building is lit electrically. 13 amp sockets are provided at frequent intervals around the walls but not above the tank. Prospective users are advised to bring several extension leads. Three-phase power is available.

SEA SPECIFICATION (See Figure 2)

The useful frequency range of the tank is .7 Hz to 2.2 Hz. There are two ways of controlling the wavemakers. The simplest is to drive them all in parallel. They follow an electrical command signal and can generate a spectrum of waves all travelling along the length of the tank. Figure 2a shows the transfer function.

However, to make full use of the wavemakers, a minicomputer (Plessey Miproc PK) is capable of controlling them individually via a serial multiplexer (A new signal is sent to each wavemaker 20 times per second and stored in a sample-and-hold circuit.) This enables us to specify:

1. amplitude of waves
2. spectrum of waves
3. directionality of waves.

1. AMPLITUDE OF WAVES

The largest possible waves are made by focusing the outputs of all the wavemakers on one point in the tank. Using this technique a trough-to-crest height of .5 m can be had at .8 Hz.

If all the wavemakers are driven in parallel, breaking waves can be made down to a frequency of 1 Hz. This corresponds to a trough-to-crest height of .22 m.

The force-feedback system incorporated in the wavemaker cancels out most of the friction in the drive mechanics, so that the wavemaker will continue to respond in a linear fashion to very small command signals (see Figure 2c).

2. WAVE SPECTRUM

The minicomputer does not generate a continuous spectrum but 21 discrete lines of a spectral curve. (We will have 70 lines available in late 1978.) These can be varied in amplitude and frequency under software control. Choice of frequency spacing can vary the repeat time of the quasi-random sea to a maximum of 54.6 minutes. Any parameters which are linear functions of the wave height can be easily processed. Data obtained by sampling a parameter for the repeat time of the particular sea running can be "perfectly" analysed by an FFT program and the amplitudes and phases of the lines resolved. Use of a quasi-random drive signal means that seas can be re-run and tests show that repeatability is good (see Fig. 3).

3. DIRECTIONALITY

Each of the lines in the spectrum can be considered a wavefront and have its direction of travel specified, provided it lies within the useable area shown in Graph 4a. The way this is done is as follows. Each of the lines in the spectrum has to be a sine wave. At any instant the minicomputer can provide wavemaker 1 with phase x of this sine wave, wavemaker 2 phase (x + n), wavemaker 3 phase (x + 2n) and so on. It can be seen that phase the phase of the wave generated i always n radians advanced .3 metres to the left. "n" is specified for each of the fronts in the minicomputer program.

The width of the wavemakers limits the angle of front that can be used at high frequency. Graph 4a shows the area of frequency vs angle that is safe: attempts to operate outside this area will result in spurious fronts occurring at other angles. These fronts are predictable and one can conceive of a very sophisticated program using them deliberately.

Each front must have its amplitude, frequency, phase increment and starting phase defined. To simplify the specification of a sea, we have developed software to run on other computers. All we need do is specify energy period or wind speed (at full scale) and the programs calculate the appropriate Pierson-Moskowitz spectrum and Mitsuyasu or $\cos^n$ spreading function. They then compute the best way of approximating these using the fronts available and produce a paper tape which can be fed directly to the Plessey minicomputer. We have a library of the more commonly used seas; changing from one to another takes no more than thirty seconds. (This, coupled with the short tank settling time provided by the beaches and absorbing wavemakers, means that there is a very short delay between experiments.) A sea not in the library can be produced in about half an hour with our 4051 computer and in a few seconds with the more powerful machines which will be available.

Currently, Mitsuyasu's spreading function is considered the best available; the software can also give $\cos^n$, which may be preferred for some work.

Additional software has been written to facilitate most simpler sea specifications.

TANK SETTLING TIME

This important parameter is a function of the coefficient of absorption of the beaches around the tank and the wavemakers. Figure 4b shows the beach performance. We have not measured the wavemakers in the wide tank since to do so would require either an opposing bank of wavemakers or a rigid reflector running the whole width of the tank in front of the beaches. What we have measured is the absorption of the prototype wavemaker in our narrow tank. This is shown in Figure 4c, and should be representative of the wide tank performance.

THE FUTURE

1. IMPROVEMENTS

Work currently in hand will boost the number of fronts generated by the Plessey to 70. This will increase the realism of the mixed seas we can produce. An interface (GPIB compatible) is being built for the Plessey which will allow it to communicate directly with another computer, rather than via paper tape as at present. This will offer two big advantages - it will reduce the time needed to change from one sea to another, and it will mean that entire experiments covering a wide variety of sea conditions can be performed under computer control.

Experiments are being carried out to find a suitable additive to clear the water in the tank. It is currently being filtered through sand but visibility is not very good and we suspect the problem has a biological origin.

2. INSTRUMENTATION

At the moment, all we can offer tank users is a cluster of three wave gauges, and NEL have had to supply anything extra themselves. We will soon be making a set of thirty three-wire wave gauges which will be positioned in front of the wavemakers. These will be plugged into a serial multiplexer and their outputs will then be accessible to the main instrumentation computer.

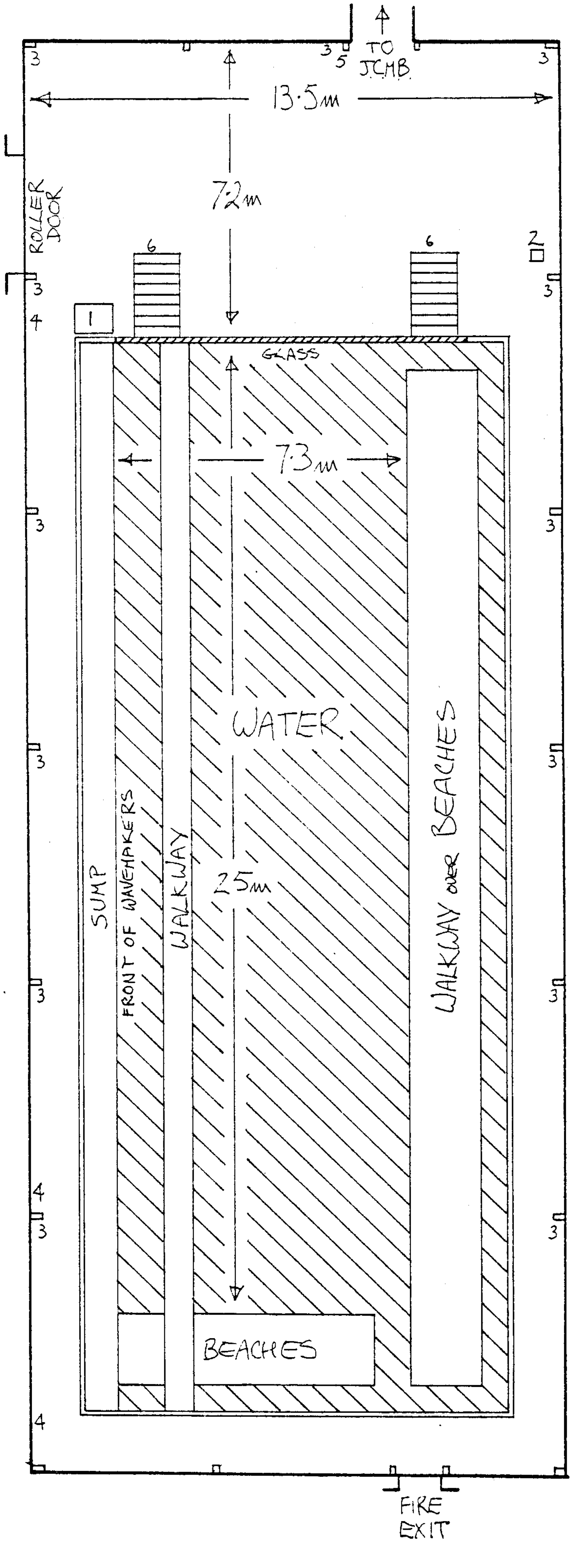
This computer has been ordered and should arrive by August 1978 - it is a DEC PDP 11/60. When it is fully operational it should be able to read and process up to about 256 channels of data in real time. It will act as a GPIB controller and thus be able to manage the Plessey. It will also be able to control the random access multiplexer system that we have already built for our TEK 4051 minicomputer. This currently gives us 64 input channels, which are distributed along the top of the beaches, but is designed to handle 256 channels. When these are all available there will be inputs to the computer all round the tank, each labelled with its own address. Longer term plans include increasing the number of channels by a factor of perhaps 4 and building another serial multiplexer for a backbone of ducks.

CONCLUSION

We were trying to build a tank which allows newcomers to concentrate on wave power without worrying about the control system. There is an elaborate safety box designed to protect the wavemakers from mistakes. Anyone intelligent enough to be working on wave power should master the system without difficulty.

FIG 1

NORTH



WIDE TANK

SCALE 1:150

KEY –

1, ±30V 500A. POWER SUPPLY

2, WATER TAP AND DRAIN

3, 13AMP SOCKETS

4, 3 PHASE OUTLET

5, TELEPHONE (EXT 2797)

6, STAIRS

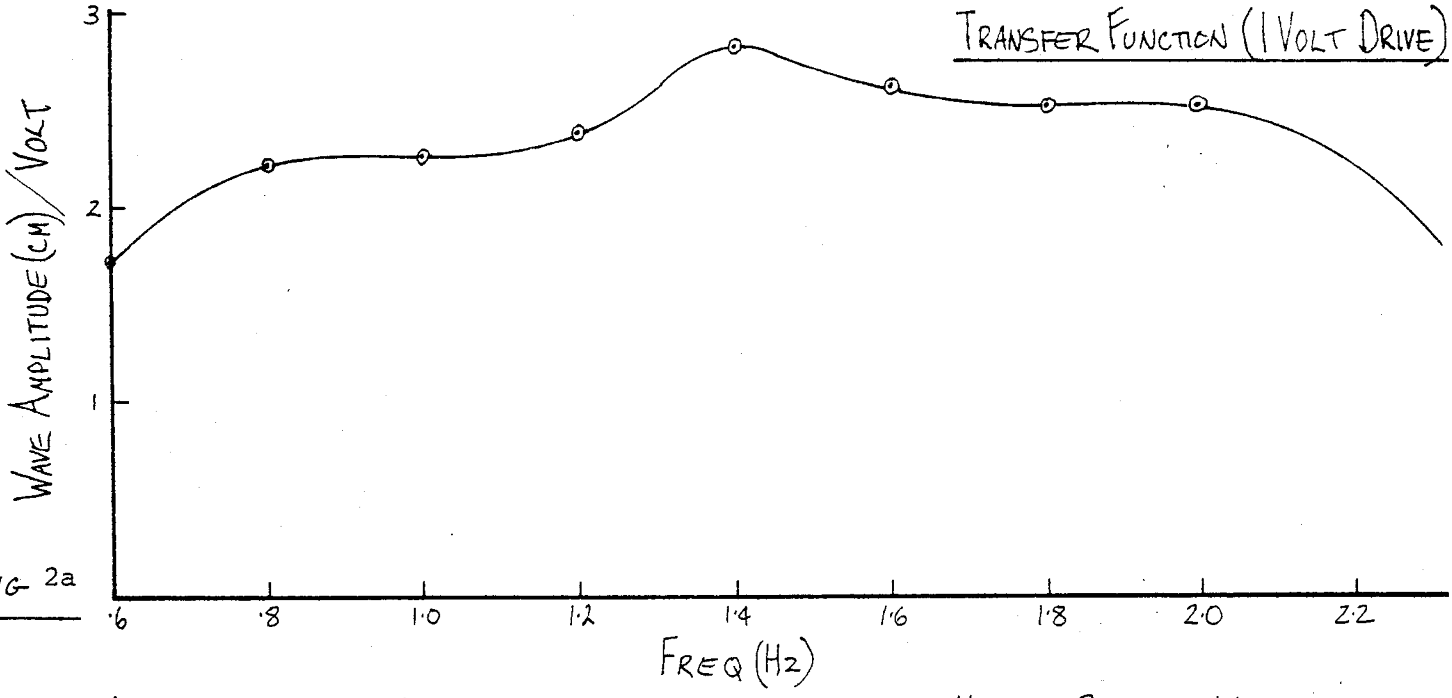


FIG 2a

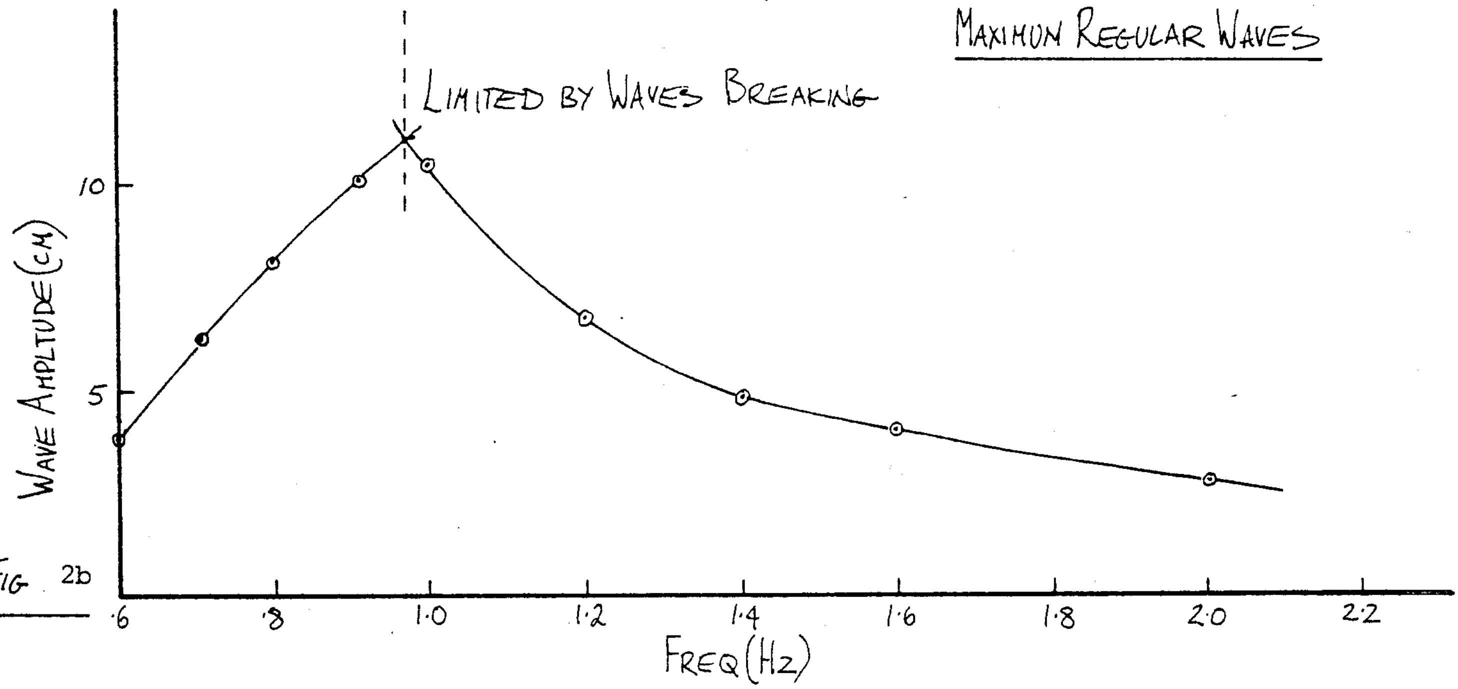


FIG 2b

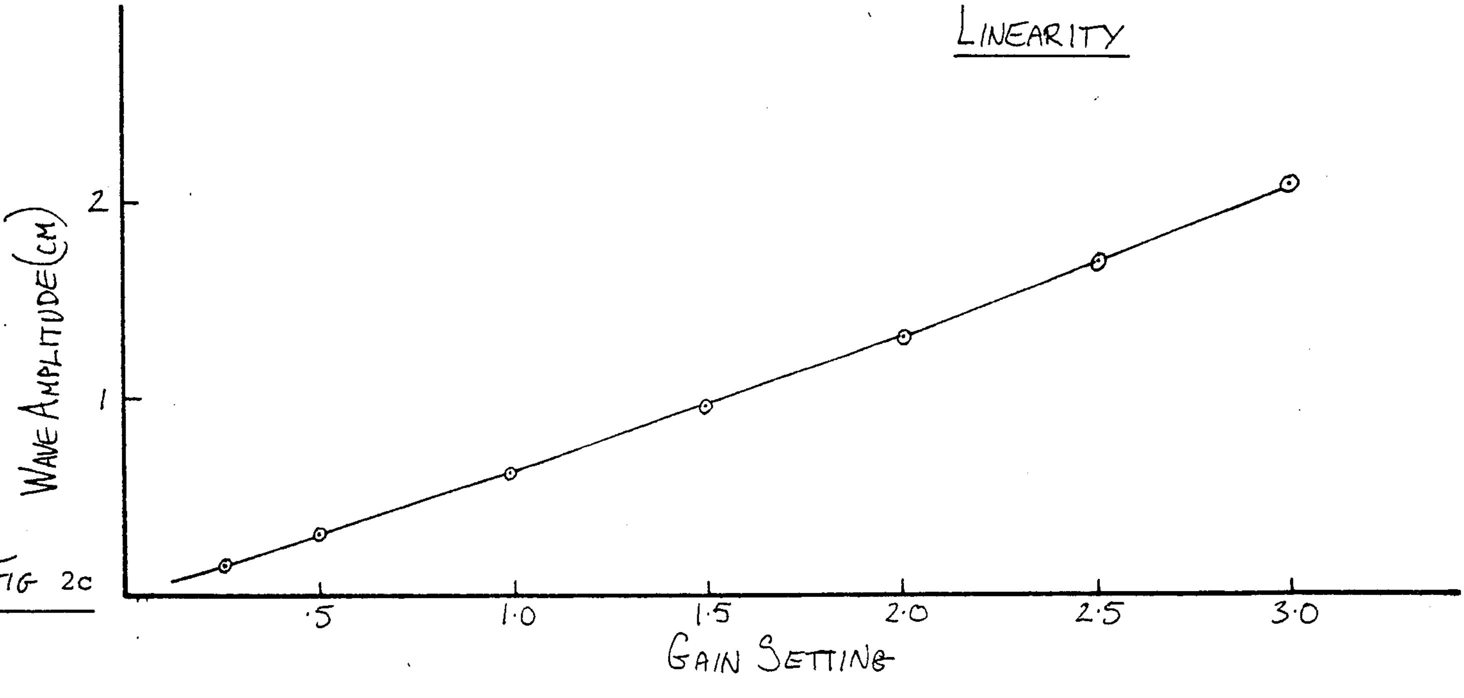
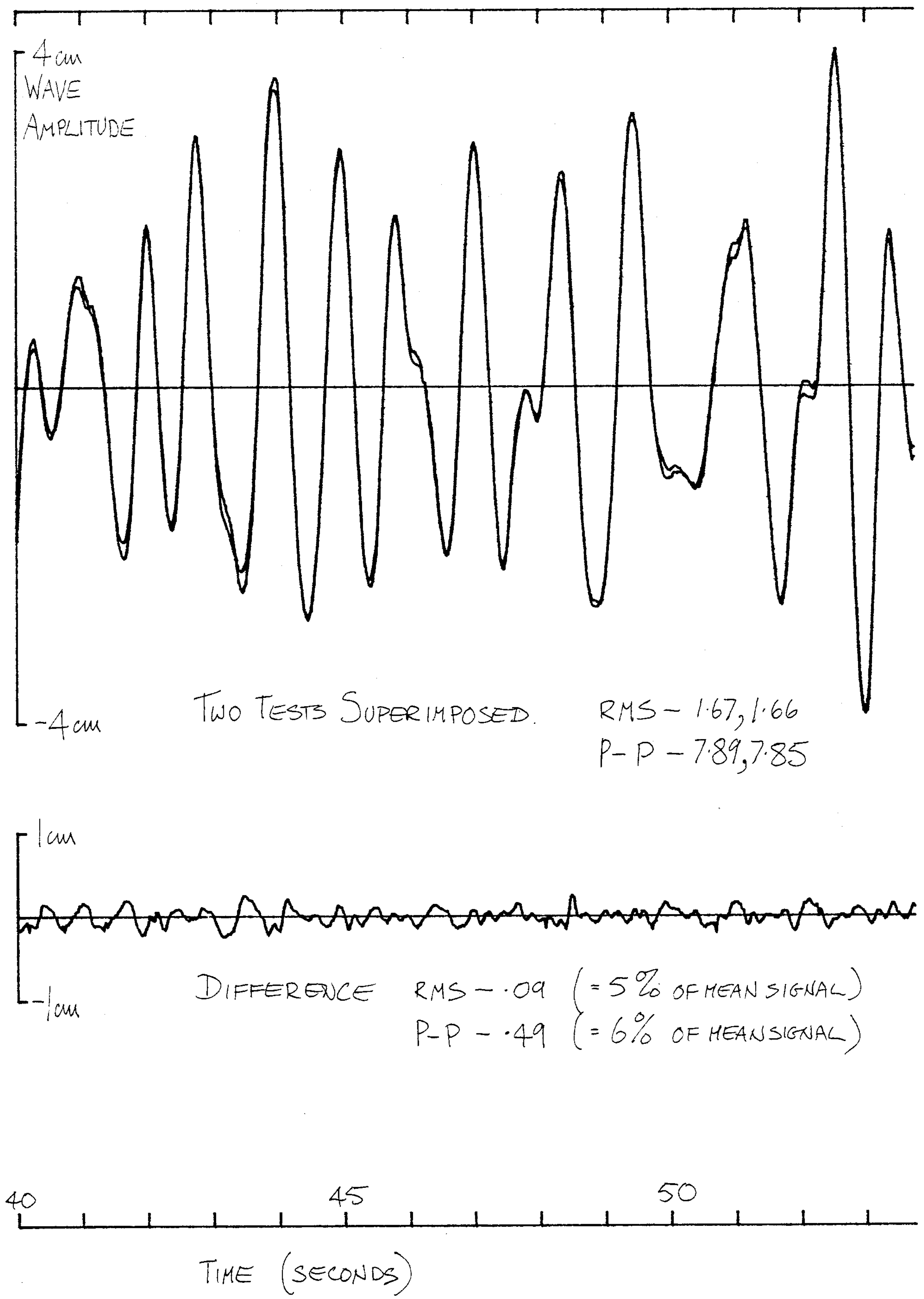


FIG 2c

FIG 3 WAVE REPEATABILITY - WIDE TANK (19/5/78)



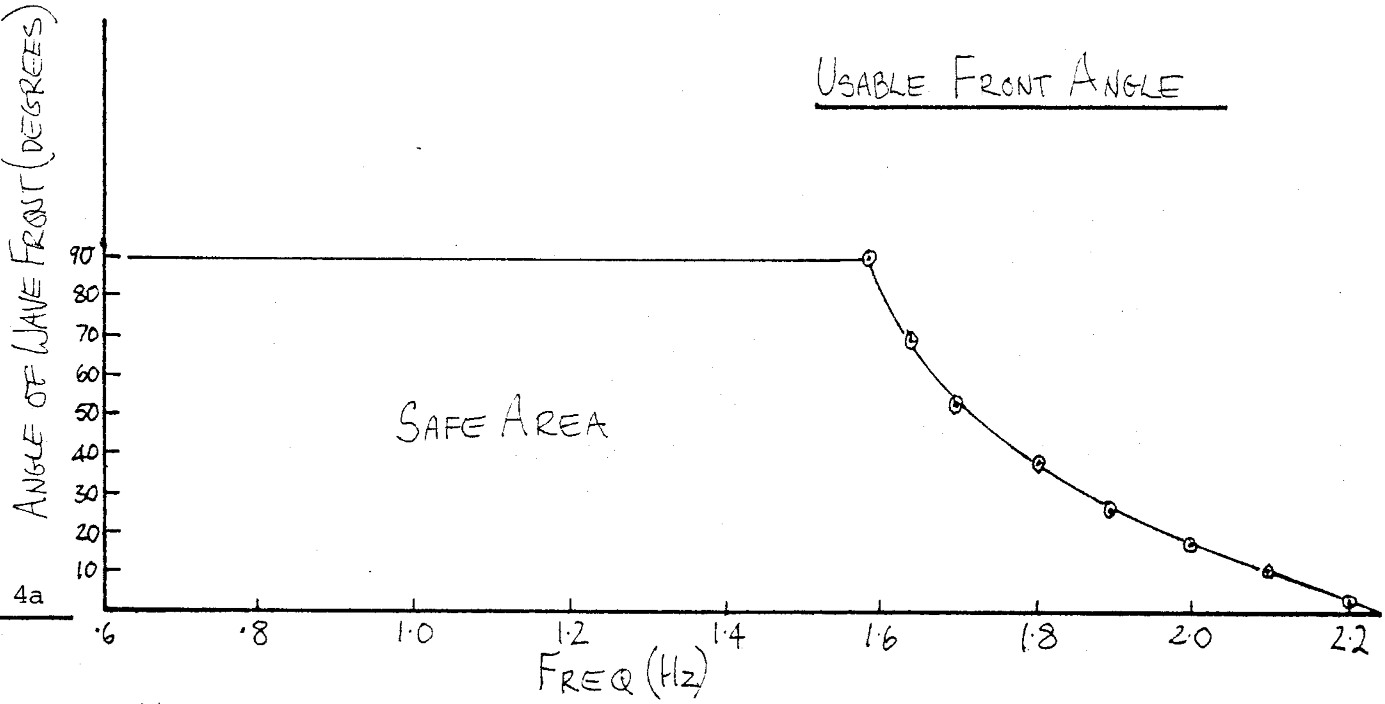


FIG 4a

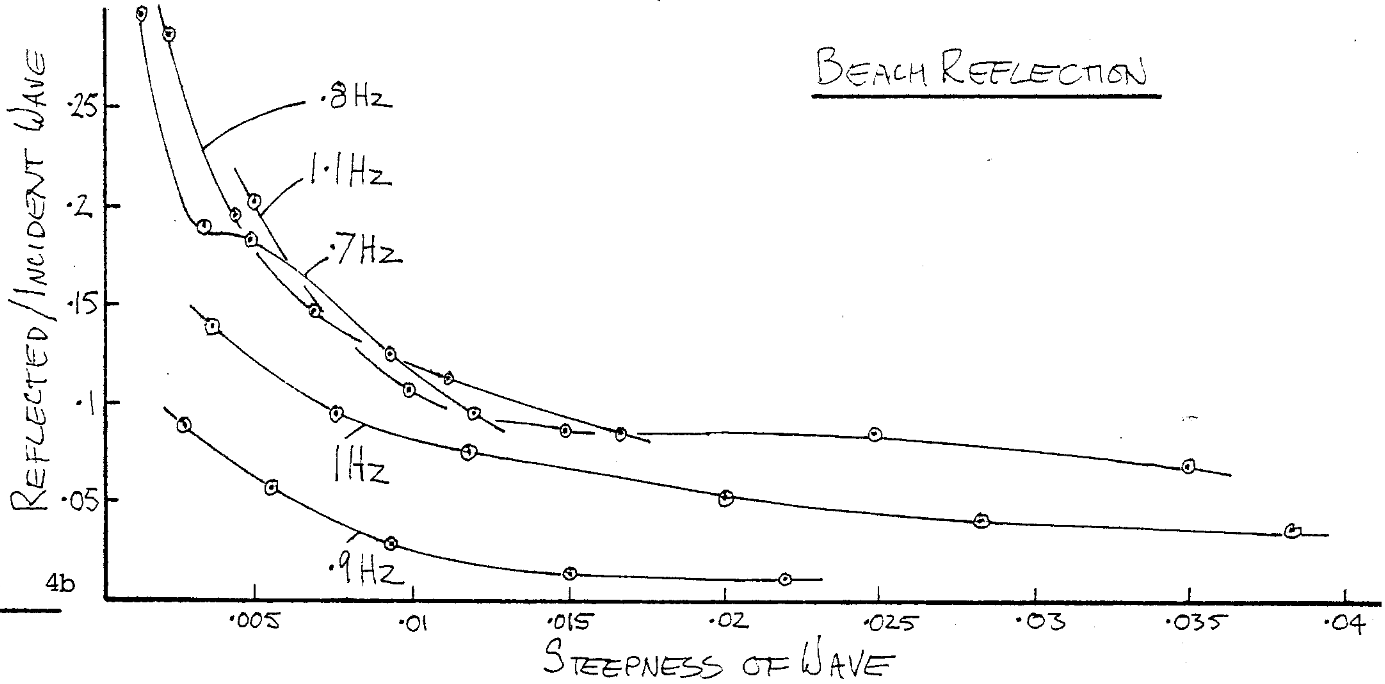


FIG 4b

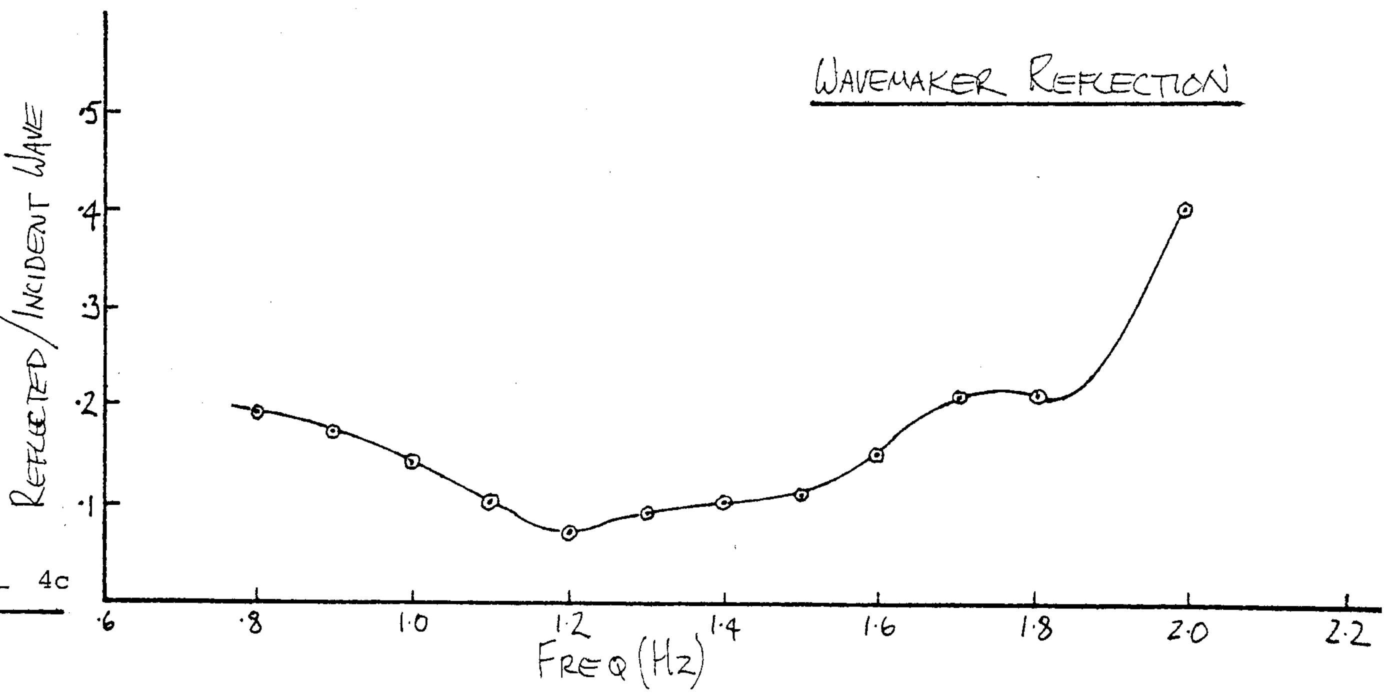


FIG 4c

SIMULATING MIXED SEAS

(1) CHOOSING FREQUENCIES

To represent a sea of spectrum E(f) by n discrete wavefronts of equal amplitude, we simply divide the area under E(f) into n equal parts. This is especially easy for the Pierson-Moskowitz spectrum because it can be analytically integrated. The wavefront corresponding to each frequency band has amplitude $a = H_{rms} \times \sqrt{2/n}$. It therefore has the right amount of energy for the frequency band it is to represent. It can also be given the right power by choosing its position to correspond to the energy period of the band.

(2) CHOOSING STARTING PHASE

We can either choose the phases of our wavefronts independently at random or so as to achieve a particular freak result which would occur only very rarely in real seas. With 20 wavefronts we can achieve a maximum of 6.3 H_{rms} (zero to peak), which would occur less than once in ten million years. (To attain a run of high waves, we also need to have a narrow spectrum.)

(3) CHOOSING DIRECTIONS

Consider first the directional spread on its own; for simplicity assume this is given by a single function of angle (unlike Mitsuyasu). We can divide the area under the directional distribution curve equally, just as for the frequency spectrum, and choose one wavefront in a direction from each sector.

Two problems arise. (a) We do not want to choose the exact centre of each sector since this would always give us exactly the same set of angles with wavefronts at pairs of mirror-image directions. (b) For distribution such as "$\cos^s\theta$" and Mitsuyasu "$\cos^m(\theta/2)$" it is easier to choose randomly than to calculate points on the distribution curve.

We get around these problems simultaneously as follows: if we want a direction representative of the m^{th} sector out of n, we simulate a set of n directions, put them in order, and select the m^{th}.

In assigning directions to different wavefronts we want a rule such that each successive group of 2 or 3 wavefronts (taken in order of frequency) represents as well as possible the overall spread of the directional distribution. This seems especially important for the Mitsuyasu direction, where we want our set of perhaps only 20 wavefronts to vary from widely spread (any consecutive 2 or 3 low frequency wavefronts) through narrowly spread (near the centre of the spectrum) to widely spread again (for any 2 to 3 high frequency wavefronts).

The rule is:

If we choose the m^{th} sector out of n for one wavefront, we choose the m + (.37n) th out of n for the next wavefront. This is completely empirical, but achieves the desired result.

This method has the further advantage that it does not matter if the directional distribution is varying with frequency (as in the Mitsuyasu case), since each wavefront is chosen relative to its own distribution. n should be small enough for economy of computing time, but large enough that the selected direction (m^{th}) does not vary too widely between simulations, as we might otherwise defeat our purpose and end up with two consecutive wavefronts from similar directions. n equal to about 20 achieves satisfactory results.

REFERENCE

(1) Gilbert, G., Thompson, D.M. & Brewer, A.J., 'Design curves for regular and random wave generators', Journal of Hydraulic Research, 9 (1971) No. 2, pp 163-196