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THE ENVIRONMENTAL ASPECTS OF WAVE POWER

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ABSTRACT

Advocates for all energy technologies must answer the following questions:

Is there enough?

Is it safe?

Is it secure?

Is it environmentally acceptable?

What are the costs?

This paper attempts to answer the questions for wave power.

Is there enough?

Waves cannot approach solar radiation in total amounts of energy but they provide greater power density than is available to wind machines. A wave installation is the second stage of a windmill of which the first stage is the open sea. The size of waves depends on the fetch of sea as well as the strength and duration of the wind. Instrument observations of waves in British waters have been made by Draper of the British Oceanographic Data Service(1). I based my first estimate of power levels on his findings. I concluded that the average power density in the North Atlantic was about 80 kilowatts per metre(2). Work in progress by Mollison and Buneman using more refined techniques suggests that it is actually more than 90 kilowatts per metre. The peak of supply is in winter. Waves are directly complementary to sun.

Visual observations from around the world have been collected by Lewis(3) and by Hogben and Lumb(4). They show that power densities in open oceans are nearly always greater than 10 kilowatts per metre. Draper(5) presents a table which shows that a fetch of 100 kilometres is sufficient to produce large enough waves to be worth harvesting. In-shore waves on a 500 kilometre front could produce all the electricity now used in the U.K. If ways can be found of transporting energy from offshore stations then the world wave potential is several times the present world demand for all forms of energy.

Is it safe?

Our designs for wave power installations are unmanned but from time to time the plant will need to be brought in for servicing. This activity will be like fishing. Men's lives will be part of the price of wave power just as we pay about one life per week for coal and twenty lives a day for road transport. With money and common-sense and sound legislation we can reduce this price. Most of the accidents will happen to yachtsmen attracted by calm water and good winds.

Most shipping keeps to the economical line between two points. This leaves very large infrequently visited polygons inside the great circle routes. Wave power installations will be more or less stationary in marked chart positions and well equipped with navigation warnings. They should be less of a hazard to ships than other ships or the land itself. However, no system of human devising is perfect and there will be many small accidents, some medium ones, and a few large ones.

Is it secure?

Security is affected by the interruption or exhaustion of the flow of some ingredient. These days we have to consider interruption by political or terrorist activity. A widely dispersed target with parallel redundant connections and controls is not attractive to terrorists. Indeed, it would take a hard-working group to make much impression on 500 kilometres of wave plant. There are no secondary hazards.

In the very long term wave power is as secure as we could wish. We know that the winds will blow for ever. In the very short term wave power is at least predictable. We know enough to prepare reliable forecasts for twenty-four hours ahead so that stand-by plant should have plenty of warning. In the medium term wave power security can be expressed in terms of a statistical probability. Figures 1 and 2 show summer and winter scatter diagrams with wave power density contours for the North Atlantic. In British waters wave power is worth having for 80% of the time, and in the winter this figure moves to 90%. The probability of zero power is not zero. The English Central Electricity Generating Board have found a week in May 1961 in which there was no wave power at a station in the Atlantic. A secondary source must be provided. There is no diurnal variation and so no match with daily patterns of demand. Methods of short and medium term storage will become important when the amount of wave power exceeds the base load.

Is it environmentally acceptable?

Wave power introduces no new chemicals or heat into the biosphere. But it does introduce a temporary diversion of heat. There will be a cooling of water on the beaches. We could measure the effects by putting a sufficient number of electric fire elements into the surf zone and noting the rise in temperature. This rather extravagant experiment is now done continuously by those generating boards who draw cooling water from the sea and put into it twice the energy that they deliver to consumers. We may also attempt calculations based on the rates of replacement of water. Stommel(6) reports a flow of 10^9 cubic metres a second in the North Atlantic drift. If this were to be evenly distributed across the western approaches then full deployment of wave power installations would not reduce the beach temperatures by more than one hundredth of a centigrade degree.

In moderate weather the size of waves to leeward of a wave power installation will be reduced to between one-tenth and one-half that of the incident ones. People using the sea lanes inshore will find life less exciting and the required levels of hardihood and seamanship will be reduced. No wave installation can absorb or reflect the extreme conditions and the very large waves with power levels above one megawatt per metre will pass unattenuated. I do not believe that the present causes of beach formation and erosion which make such a large difference between the east and west coasts of the Hebrides should be much affected. But if they were then we have many examples of beaches in sheltered seas to help us predict the outcome. The wave power engineer will, if he can, avoid sites with high current flows. If mistakes are made and silting of harbours results then the machinery may be re-sited at little expense.

Among the many requirements of modern industry are power, cooling water, deep harbours and easy disposal of waste. Some industrialists may feel that threats of nationalisation and factory regulations restrict their freedom and they might be tempted to set up at sea. I believe that waste disposal from an offshore installation in international waters could be dangerous and difficult to regulate in the present state of international law, and that this is the only serious environmental risk inherent in wave power. Perhaps this risk is really inherent in having industrialists.

What are the costs?

To calculate the cost one should add up cost of research and development, land, factories, processing plant, fuel, labour and interest charges that can fairly be carried by the project, and divide this by the output produced over some period of time. This tedious exercise is not always done amid the excitements of technological advance. The answer is most needed at the start to help in deciding between competing proposals, but cannot be known with any certainty until the end. It is particularly difficult to decide whether or not some piece of research done many years before has to be paid for by this account or another.

We set out to build Atlantic plant rated for an average of 50 kilowatts costing £20 000 (1974) (October) per metre giving a target capital cost of £400 per kilowatt. After considering a wide number of possible mechanisms and conducting model tests of several, we settled on the one shown in Figures 3 and 4. It consists of a number of 'duck'-shaped segments rotating about a common backbone. Each duck is designed to be slightly heavier than the water it displaces so that if it should

IMPLIES HIGH EFFICIENCY - SEE SALTER'S NATURE ARTICLE break it will sink. The whole structure has a very low freeboard so that it could be easily submerged. The rear surface of each duck is a cylinder coaxial with the centre of rotation so that no water is displaced behind and no rear wave created. The front curve is designed to match the displacements of water in approaching waves. The natural 'nodding' period is designed to coincide with that wave period where maximum efficiency is required and attempts are made to broaden the frequency response. Laboratory tests on single units show an extraordinary efficiency for monochromatic and mixed spectrum waves.

In full scale designs prepared by my colleague Eric Wood each duck runs on rollers which are the bodies of commercially available rotary hydraulic pumps(7). High pressure oil drives hydraulic motors and electrical generators at sea. Each metre length displaces just over one hundred tons. One unit will be about 500 metres long. The concrete, the electrical generating plant, the hydraulic parts and the labour can all be costed fairly accurately. The result is within the target. The only problem lies in the strength requirements of the common backbone. The laboratory models are mounted on fixed bearings. At sea this reference must somehow be synthesised. It is clear that a sufficiently long backbone would span a large enough sample of wave phases so that it would average the alternating components of wave force. But the resulting structure would suffer a dangerous bending moment in the centre. We calculated that the really extreme '50 year wave'(8) would require steel costing ten times more than we could afford. The crucial question was whether we could find ways of evading those bending moments. The key to the problem has been found by Eric Wood. His design gives a rigid backbone for low bending moments which turns into a flexible one for high bending moments. A model tested in a multidirectional sea behaved as we had hoped.

Our approach is by no means the only one, and efficiency itself is of no concern when the gods pay for the waves. But in structures of this size the wave forces depend on the displacement, and the cost depends on strength, so that there are powerful economic incentives to get the most power out of the lowest displacement. We are certainly interested in the highest possible efficiencies for those times when wave power levels are low.

Wave power plant can be added in amounts of £10 000 000 at a time. All engineers make mistakes. If we are wrong we can be stopped early. Wave power plant consists of multiple small modules which will have the advantage of repetitive production. Each will take only a few months to build so that interest during construction is low. The makers of the hydraulic parts advise us that we will need to replace bearings and seals after six years. Ships need antifouling treatement after two years. This work will have to be done in protected water and will be the major running expense. Ships can be made to last for forty years and indeed, the first ferro-cement boat made in 1855 is still in perfect working condition.. It is an obvious disadvantage of wave power that almost all the costs come at the beginning but that benefits may accrue to future generations.

Chapman(9) gives figures for the energy content of raw materials. Structural steel consumes * ~~132 000~~ kilowatt hours per ton while cement needs 2 200 kilowatt hours. If we use a five to one aggregate ratio, we will need to run our plant for 2 000 hours to earn the energy to build it.

* SHOULD BE 13,200 Kwhr/ton

1 UNIT 50 kw/metre COST TARGET £400/kw ⇒ £20,000/metre

1 METRE LENGTH DISPLACES 100 TONS ; TOTAL LENGTH 500m

NOW REPAYMENT TIME = 2.000 hours

∴ Energy cost = 50×2,000 = 100,000 Kwhr/metre

⇒ 1,000 Kwhr/ton

Conclusions

I claim that the answers to the questions at the beginning of this paper are as follows:

There is enough wave energy.

Its safety is acceptable. The dangers are clear and well understood.

Its security is as good or better than other technologies.

Wave power is clean and cool.

As model work continues, the cost estimates continue to fall. If all costs are considered it is already competitive for good sites.

I rest my case. Let the ultimate judges be our children and, of course, the sea.

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Acknowledgment

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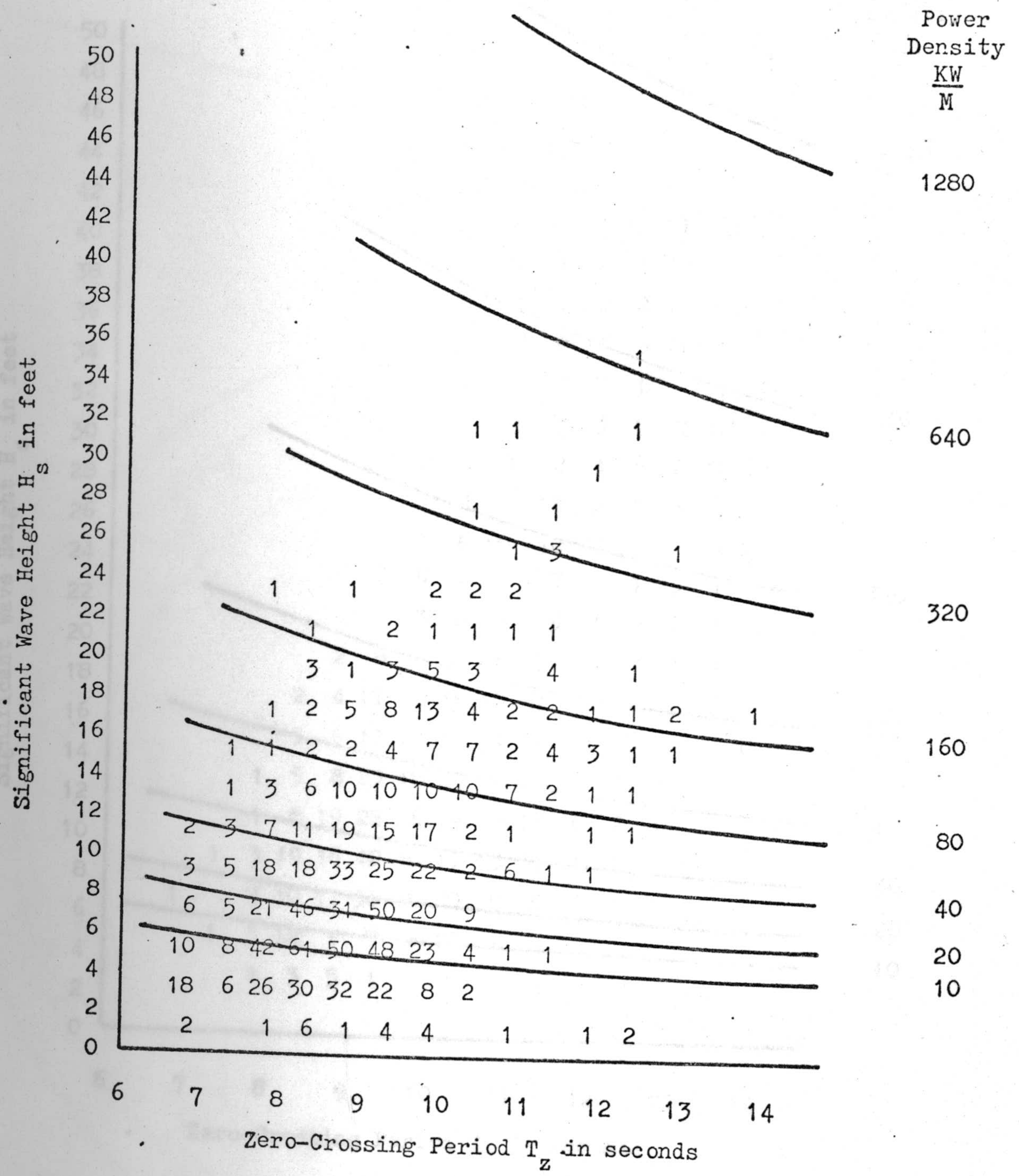
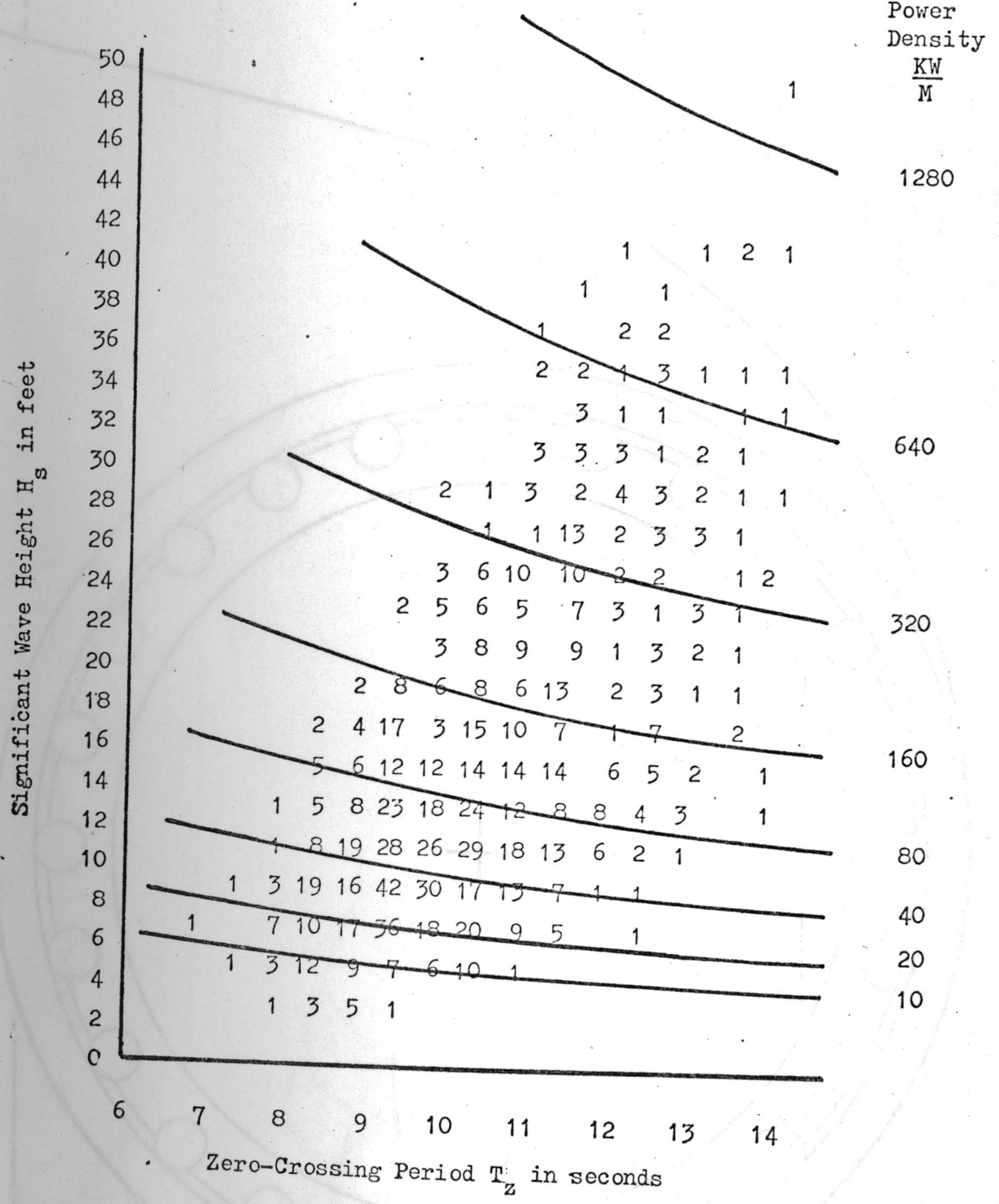


O.W.S. 'INDIA' SUMMER

FIGURES 1 and 2

Data is based on observations made by The British Oceanographic Data Service between 1955 and 1965. The isodynes show power density levels in kilowatts per metre. Each entry represents the number in parts per thousand of a particular combination of significant wave height and zero crossing period.



O.W.S. 'INDIA' WINTER

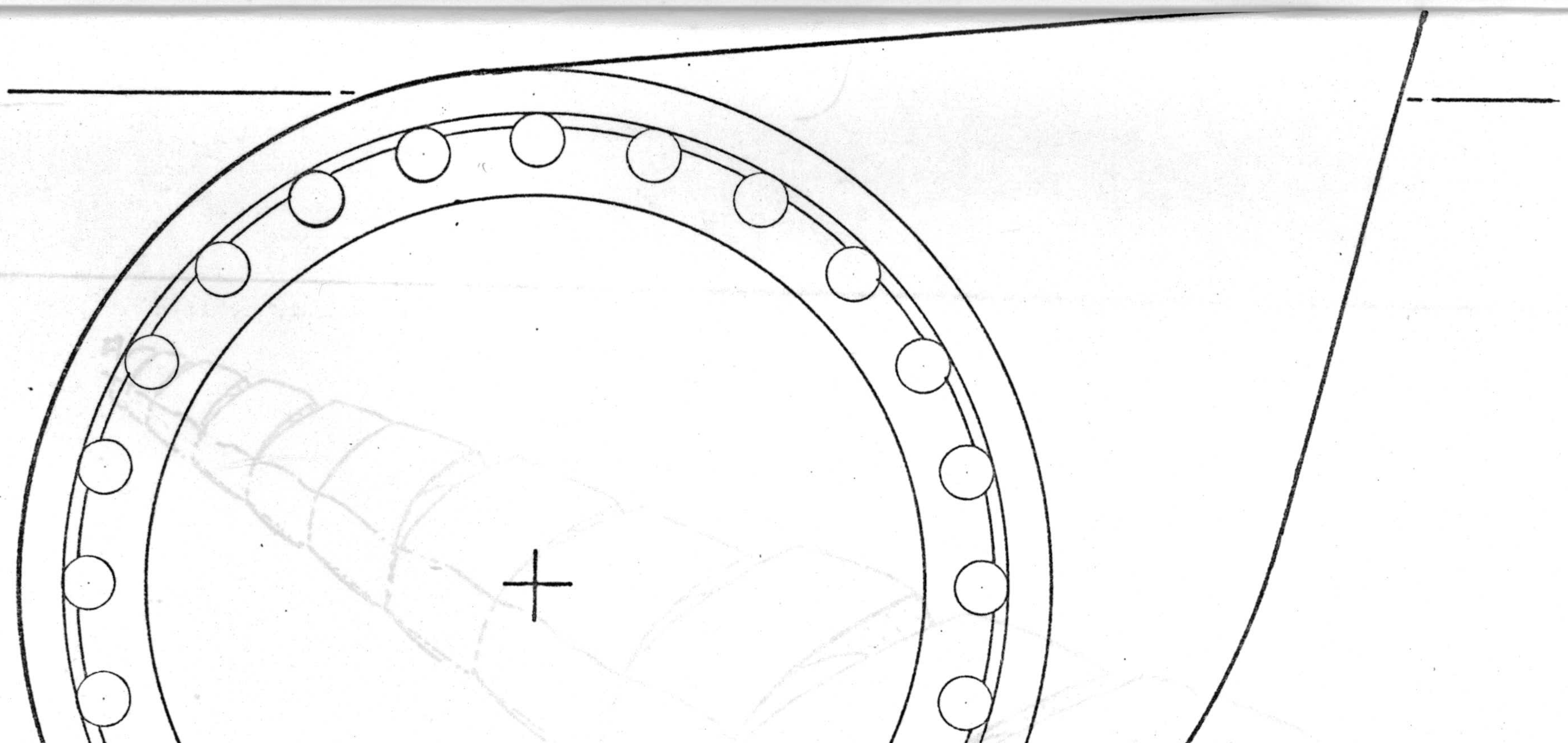


Figure 3

A cross section of duck and backbone and hydraulic rollers. The diameter of the rear portion will be about 10 metres.

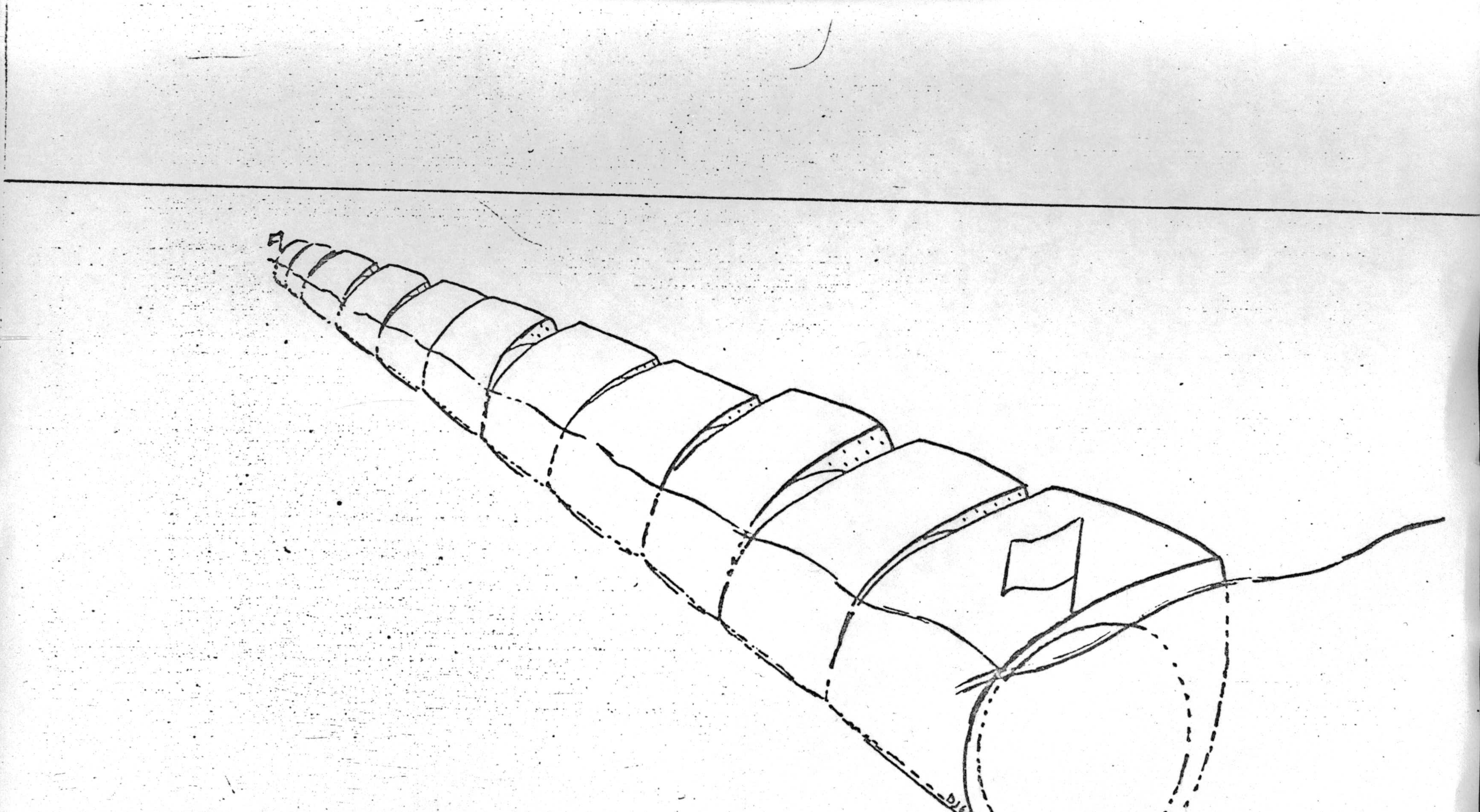


FIGURE 4

ARTIST'S IMPRESSION OF
FULL-SCALE EQUIPMENT AT SEA.