RENEWABLE ENERGY

FRAME DESIGN OPTIONS FOR A CIRCULAR CLAM WAVE ENERGY DEVICE

Figure 1

This is a summary of a project undertaken by a consultant in support of a review of wave energy for the Department of Trade and Industry.

Objectives

- To build on work undertaken between 1983 and 1986 by developing the structural design for the reference frame of a Circular Clam wave energy device.
- To identify and explore a number of specific design options including:
  - an open three-dimensional frame similar to the 1986 design
  - a closed steel hull
  - a closed concrete hull
  - a composite hull.
- To assess the costs of construction, of site or temporary works, and of launching, for a production run of 10 devices.
- To consider options for flexible membrane air 'bag' support.

Contractor's Report

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Frame design options for a Circular Clam wave energy device (1992).

dti

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Main Conclusions

- There was little difference in the costings for the steel (£1.23–1.60M per device) and concrete (£1.25–1.88M per device) hull structures.
- The tubular steel frame option was considered to be less efficient and more costly to fabricate than an equivalent steel hull structure.
- The two composite designs investigated were expected to be more costly than either the steel hull or the concrete hull structures.
- The steel hull design is within the construction capability of a number of existing shipyards. Several construction options are available for the concrete structure.

The Project

Background

The Circular Clam wave energy device is a floating toroidal dodecagon (see Figure 1) with rectangular air cells formed by flexible bags attached to the outside of the structure. The air cells are connected to each other by a manifold which passes around the whole structure. Differential wave action around the device causes air to be pumped between cells via the manifold. Power is extracted via air turbines which are mounted in the manifold between neighbouring air cells.

The Circular Clam wave energy device was initially developed in 1983, and a representative model was tested at the end of the following year. Although the tubular steel design was considered to be more efficient and cost-effective than the original straight Clam device, it was in no way regarded as the optimum. A subsequent assessment, by Rendel Palmer & Tritton Ltd (RPT), resulted in the proposal of a number of design modifications to ensure that the structure had an economic design life. In 1991 consideration was given to the design modifications suggested by RPT. Work undertaken by the company has involved the generation of a number of alternative design options. The three envisaged at the start of the 1991 project were:

- an open, 3–D, tubular steel framework, similar to the 1986 design
- a closed steel hull
- a closed concrete hull.

Progress made with the two hull schemes made it clear, at an early stage, that there was little to be gained from the continued development of the tubular steel design. The steel hull concept, for example, was found to be only 5% heavier than the tubular design but to cost 30–50% less to construct. The decision was, therefore, taken to consider a composite hull option.

Two composite designs were considered. In one, the lower section of the device comprised fabricated steelwork and the upper section concrete. In the other, a concrete layer within a steel hull of reduced thickness provided the necessary hull strength. Neither scheme was considered to offer a cost advantage and the main focus of attention has, therefore, been the two closed hull designs.

Certain design constraints were imposed at the start of the 1991 project, to ensure that the structure's performance would not differ substantially from the original 1986 design. These included:

- overall device dimensions, (diameter, depth) similar to the 1986 design
- a flexible membrane air 'bag' geometry similar to the 1986 design
- a 'clean' inner duct, with one turbine to each of the 12 Clam sections
- the provision of adequate residual buoyancy and of bulkhead subdivisions to improve stability in the case of damage.

No attention has been paid to moorings, to mechanical and electrical equipment or to the design of bag attachments, although some consideration was given both to the power ducts between turbine units and to possible means of bag support.

Assessments have been made of the costs of construction, of site or temporary works, and of launching. No costs have been provided for towing or for final installation. The costs assume a production run of 10 devices.

Proper consideration has been given to the Clam's stability, both when intact, and after damage, and the designs developed were found to be satisfactory in this respect.

The designs have also taken into consideration both wave load analyses and stability modelling. The latter again gave satisfactory results for the Clam, both when intact and after damage.

The Steel Hull Design (Figure 2)

The steel hull design is made up of 12 modules separated by watertight bulkheads, each module forming one side of the 12-sided structure. Each module supports one flexible membrane bag and contains one turbine cell to which access is gained via a hatch in the deck. The turbine cell occupies the upper section of the central third of each module and is isolated from the

Figure 2

rest of the module by watertight bulkheads and a floor. The turbine cell is designed to contain the turbine pod, the switchgear, oil coolers and other ancillaries. The rest of the hull in each module forms a single cell which will be fully ballasted with inert water when the device is operational. A continuous power duct passes through all bulkheads with branches off to each air bag.

The reverse curved front of the module forms a recess designed to suit wave power extraction requirements. The rim of this recess is shaped to accept a steel attachment frame for the air bag.

The design allows hull construction to follow normal shipbuilding practice as closely as possible and to make use of a yard's existing panel lines, jigs etc. An assessment at one shipyard showed that each device could be constructed under cover in two halves, the two halves being joined outside. Such a procedure would allow all mechanical and electrical fitting out (apart from the final interconnection between the two halves), duct-work, painting and testing to be carried out under cover, in a controlled environment.

Each device, as constructed, is relatively light and has a draught of only 1.5m. Provided at least this depth of water is available at the quayside, it can be launched down a slipway of adequate width.

The structure will require regular inspection and maintenance:

- annual inspection surfaces and mooring attachments
- inspection of bag recesses whenever bags are changed
- monitoring of cathodic protection of ballast tanks
- painting of external surfaces and the bag recess at five-yearly intervals.

Ballast adjustments can be made using portable pumps powered from a maintenance vessel. Such adjustments allow part of the hull to be raised clear of the water so that inspection and painting can be carried out in situ, provided the weather is calm.

Access for a limited amount of internal maintenance is provided via a manhole in each power compartment. The turbine generator power pod and other large ancillary components can, if necessary, be removed via a specially designed hatch for maintenance ashore.

Costings have been based on quotations from the UK, Germany and the Netherlands. The range of tender costs for the 920-tonne steel hull, allowing 10% for contingencies and structural fitments, is expected to be between £1.23 million and £1.62 million at second quarter 1991 prices. These figures do not include design costs, mooring, mechanical and electrical equipment, or the bags and their attachments.

The Concrete Hull Design (Figure 3)

The basic design of the concrete hull is the same as that for the steel hull. Twelve modules, separated by watertight bulkheads, each form one side of the 12-sided device. However, in the concrete design, each module is divided by a horizontal mid-height floor and two intermediate bulkheads into six watertight cells. Each module supports one flexible membrane bag connected

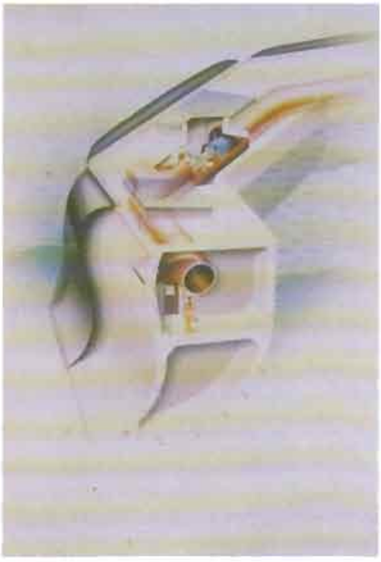

Figure 3

by a single branch duct to a 1.5m diameter common manifold duct. The turbine pod, switchgear, oil coolers and other ancillaries are located within the central upper cell of each module. A bag recess is provided at the rim of the reverse curved front of the structure.

The hull width of each module is slightly greater than for the steel hull, in order to produce sufficient buoyancy to support the additional weight. Wall thickness is a minimum of 300mm. Internal stressing has been preferred, and high tensile steel wire tendons have been assumed. Alternative tendon materials, notably glass fibre and aramid fibre, offer certain advantages: they are lighter, and they are virtually non-reactive in an aggressive environment. Glass fibre tendons can also be monitored using fibre optic techniques. Both materials, however, incur greater relaxation losses (5–6%) than steel and are also more costly.

A number of basic construction options have been considered.

Construction basin

Although large offshore construction basins are capable of handling complete devices, their size and operating cost is such that the construction of a single device in such a location would be uneconomic.

Graving dock or slipway

By constructing the device in one-quarter or one-third segments, the required dock-width is reduced. With four segments, for example, the width is reduced to about 14m, and several dry docks exist which are now disused and which could accommodate such a method of construction. The device would, however, have to be assembled afloat and would require double bulkheads at the segment ends.

Submersible pontoon

A number of submersible barges exist which could be used to transfer the Clam into the water. There are two options:

- to assemble the device in segments on two adjacent beached or floating pontoons
- to slide the completed device onto the pontoons after construction on land, thereby minimising pontoon hire charges.

Purpose-made submersible pontoon

A purpose-made pontoon would need to be approximately 65m square and submersible to over 8m over the main deck. It would be moored alongside a jetty to provide access for men and materials, and the device would be constructed on board. This option would only be cost-effective for a very large production run.

Temporary steel pressure dome

The device would be constructed in a bunded area approximately 4m below mean high water level in an area where the tidal range exceeds 4m. A steel pressure dome would be bolted over the completed structure to form an airtight seal. With the bunding removed, the water level would rise, compressing the air inside the dome. The device would float with a draft of about 3.2m. Once in deep water, the dome would be vented and removed.

Concrete hulls require much less structural maintenance. Nevertheless, regular maintenance will be required, including:

- annual inspection of internal and external surfaces, stressing anchorages (where accessible) and mooring attachments
- inspection of bag recesses whenever bags are changed
- where appropriate, the three-yearly removal for inspection and replacement of a sample number of removable greased external tendons.

Internal maintenance options are similar to those for the steel hull.

Cost estimates are for civil works only, assembled floating and moored off the west coast of the UK. They are based on a production run of 12 devices. There is no allowance for escalation or price contingency, although a 15% contingency has been allowed for design and construction. Estimates are in the range £1.25–1.88 million at second quarter 1991 prices.

The main parameters of the structures are summarised in the table below.

	Steel hull	Concrete hull
Device width at widest point	60.0m	60.0m
Hull width (average)	4.0m	4.5m
Hull depth	8.0m	7.9m
Total displacement weight (with ballast)	4,489.0t	5,240.0t
Draught (bags deflated)	7.4m	7.4m
Reserve buoyancy (bags deflated)	330.0t	388.0t
Materials quantities:		
concrete		$1{,}900.0m^3$
reinforcement		290–310t
pre-stressing		50.0t
structural steel	920.0t	32.0t (duct)

Cost

£49,000 – 100% funding from the Department of Trade and Industry

Duration

Twelve months – completed March 1992

Further Information

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