Energy Technology Support Unit - Harwell

Department of Energy

Appraisal of Mass Production Costs for Wave Energy Devices

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March 1980

APPRAISAL OF MASS PRODUCTION COSTS FOR WAVE ENERGY DEVICES

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1. INTRODUCTION

In 1979, ETSU were concerned about conflicting information on the cost of Wave Energy Devices. They doubted that the Quantity Surveyor approach to costing was appropriate for such a large ongoing demand and wished to obtain opinions from experts in setting up and working in mass production industries.

WESC and the Department of Energy authorised a study to be undertaken by The P-E Consulting Group under the direction of ETSU. The Terms of Reference for this study are:

> "To express opinions on the order of possible costs obtainable by adopting a mass production rather than a traditional approach to the construction of Wave Energy Devices"

The study was to be restricted to the:

- costs of manufacture and launch of the hull structures
- consideration of the mass production cost reduction obtainable by using steel or concrete as construction materials

The budget for the study was very limited and it was therefore essential to restrict the study by taking an overview of a sample of representative devices without getting involved in their design and development.

ETSU advised that the devices to be considered were the:

Cockerell Raft

Lancaster Flexible Bag

Salter Duck

Through the ETSU Project Officers and the Device Contractors we collected data on the latest designs and visualisations of the devices and the method of manufacture. Discussions were not held with Rendell Palmer and Tritton (RPT) since they were deeply involved at this time in assessing and reporting on the 1979 progress of the device teams. However, we held useful discussions with many interested people at the Workshop in December which we found both helpful and stimulating.

To maintain an independent view we have used where possible our own sources and contacts in industry to discuss manufacturing techniques, material costs and technical developments. We have also held 'in-house' brainstorming sessions using our staff of different professional disciplines with varied manufacturing and mass production experience to ensure as broad an input as possible to the study.

We have not examined or commented on the detail design of the devices, their planned output or the question of energy balance. Our reference production rates were based on a ten year manufacturing programme aimed at achieving an output roughly equivalent to a 2 gigawatt power station. These production rates current in the Autumn of 1979 are expressed in units per annum as:

Raft - 80

Bag - 32

Duck - 102 ducks on 51 spines

Illustrations of these devices are included as Appendix 6 at the back of this report.

The level of sustained demand for these very large devices calls for a mass production factory approach to manufacture for which neither the construction nor the ship building industry is currently geared. This report indicates some concepts on the approach to manufacture which we believe must be adopted if Wave Energy Devices are to be produced at the lowest cost.

2. SUMMARY

2.1 The manufacturing cost can be considered as made up of five elements: Materials, Labour, Capital, Overheads, Commercial.

2.2 Decisions on design and production concepts will alter the balance of these five elements and hence the manufacturing cost. It is important to understand the effects of these decisions so that an optimum cost is achieved.

2.3 In addition to the basic cost, the eventual price must take account of risks and in manufacturing the 'cost risks' can be expressed as excesses in:

- waste of materials
- rejection of parts and assemblies
- stoppages of labour and plant
- shortages of material and labour.

An optimum manufacturing strategy must amongst other subjects ensure that these risks are minimised so as ultimately to result in the lowest cost.

2.4 Manufacturing risks can be reduced by careful planning and by taking the best decisions on such subjects as:

- raw material inventory
- quality control
- testing
- industrial relations
- planned maintenance
- duplication of facilities
- buffer stocks
- absenteeism and holidays
- method of manufacture.

2.5 The manufacturing location will affect costs through three main influences:

- capital grants
- productivity and labour rates
- material distribution

2.6 We believe that to plan a minimum cost approach and subsequently maintain it, will necessitate working in a business environment with cost targets, variance control and a profit motivation.

2.7 The principal benefits of a mass production approach will come from the cost optimisation of three main concepts:

- a product designed for production
- bespoke facilities
- mechanisation and automation.

2.8 With the size of the Wave Energy Programme there is scope for reducing overall costs by a vertically integrated approach to all the cost elements from raw materials to tow out and commissioning and not restricting the examination to the manufacturing facility. In particular, labour factors, material sources and transportation should be thoroughly considered.

2.9 Designing in steel can produce benefits from mass production manufacture. The main drawbacks are the high material cost and the need in most applications to provide surface protection to prevent corrosion.

2.10 Concrete designs are less suitable for cost reduction from mass production manufacture unless the products are small and simple in shape (basically two dimensionally shaped). The advantage of concrete is that it is a relatively cheap and durable material.

2.11 All materials are readily available in the UK to satisfy the manufacturing requirements for any of the three devices.

2.12 A mass production approach could achieve productivity levels of less than 10 man hours per tonne for the Raft and Bag in both steel and concrete. The figure will be higher for the Duck due to its more complex shape.

2.13 Mass production will require a large capital investment. Our estimates range from £85-125 million depending on the device design, location and beach configuration.

2.14 Our estimates of the material cost per tonne for the three devices are:

		Raft	Bag	Duck
Steel	£ per tonne	209	--	250
Concrete		45	27	43

The rubber bags add a further £19 per tonne to the Bag making the total material cost £46 per tonne.

2.15 Our estimated device costs use an overhead element equal to 15 per cent of material and labour costs and a commercial element based on interest rates of 16 per cent p.a. and a profit on turnover of 4 per cent.

	RAFT		BAG	DUCK
	Steel	**Concrete**	**Concrete**	**Concrete**
Manufacturing cost (£ per tonne)	353-386	113-124	139-152	166-182
Weight (tonnes)	5,000	13,000	10,600	4,300
Device cost structure only (£ millions)	1.77-1.93	1.47-1.61	1.47-1.61 (1)	0.71-0.78 (2)
No. of devices for 2 gigawatt (3)	800	800	320	510
kW/tonne	0.50	0.192	0.588	0.912
2 gigawatt cost (£ millions)	1416-1544	1176-1288	470-515	362-398
Structure cost/kW (£ per kW)	706-772	588-645	236-258	182-199

Notes

(1) The Bag costs include the rubber bags.

(2) The Duck costs are not representative as they exclude: spine joints, Duck beaks and power generation pod.

(3) Figures current during the study but subsequently altered.

2.16 The estimated cost of some £370 per tonne for a steel Raft represents a significant saving over current 'one off' fabrication costs.

2.17 The estimated cost of some £120 per tonne for a concrete Raft does not represent a significant saving over current insitu construction costs.

2.18 A design for production approach to concrete which would simplify construction insitu would seem to be the objective requiring further work if significant mass production benefits are to be obtained.

2.19 Like any product development programme once the conceptual design is established and the development work is in hand there is a need to monitor costs on a continuous basis in order to establish priorities and avoid the costs of wasted effort on non viable work.

2.20 There is greater scope to reduce the cost per tonne by mass production in steel compared with concrete. However the total device cost will depend on many factors of which mass is the most important. In the end the critical ratios will be the cost/tonne and kw/tonne for a particular device and hence the cost/kw.

3. APPROACH TO MINIMUM COSTING

This report is principally concerned with the questions of manufacturing costs and how they can be minimised.

3.1 The Elements of Cost

Therefore let us first introduce a cost model which we will use in all later analysis and which considers the total manufacturing cost of each unit to be made up of five elements:

Materials	X
Labour	X
Capital	X
Overheads	X
Commercial	X
TOTAL COST	XX

These elements are defined as:

Materials - The cost of all permanent materials

Labour - The cost per unit of all labour involved in the manufacturing process including direct production, material handling, maintenance operators, indirects, supervision and including all employment costs.

Capital - The apportioned cost per unit of the total capital debt for plant, equipment, buildings and replacements amortised over the life of the manufacturing programme (assumed as 10 years). This cost excludes interest on capital.

For example:

Capital expenditure for 10 year programme	-	£100 million
Output of devices in 10 years	-	1,000 units
Capital charge per device	-	£100,000

Overheads - This cost includes all other expenditure incurred at the manufacturing facility with the exception of financing charges:

- management and administration
- building overheads
- energy
- insurances
- consumables

Commercial - The apportioned cost per unit of financing charges and profit.

During the course of this short report several ideas and concepts will be put forward which will have an impact on one or more of these elements. It is important to understand the effect on the total cost of these concepts and where benefits are gained and penalties incurred. In the end an optimum solution must be decided.

3.2 The Concept of a Cost Optimisation

Consider the following examples of cost balancing which are discussed later in the report.

- a design for production approach will simplify some manufacturing processes, reduce the labour and capital requirements, but is likely to increase material costs

- a move to mechanisation and automation will increase the capital cost and therefore also the commercial costs but aims to obtain reductions in the labour and overhead costs

- a production strategy which works a plant 2 or 3 shifts a day increases labour costs but maximises the use of capital and hence reduces commercial costs. It could impose greater risks.

The interrelation of the manufacturing strategy with design concepts and production concepts is very complex. It is essential that a business approach is adopted to the reconciliation of these factors in the strategic plan if a minimum manufacturing cost is to be achieved.

3.3 Manufacturing Risks

In the context of overall manufacturing strategy the importance of 'risk' and its effect on costs cannot be ignored. A strategy that minimises risk will ultimately minimise cost. Above the normal costs of manufacturing the cost risks can be expressed as the effect of excesses in such items as:

- waste of materials
- rejection of parts
- stoppages of labour and plant
- shortages of material and labour

Each has a direct influence in the unit cost of the product but far more seriously these factors aggregate during the manufacturing processes and result in a failure to meet production targets and provide the need to plan for increased capacity. In a capitally intensive mass production approach, failure to produce will significantly increase the unit cost by adversely affecting the capital, commercial, labour and overhead elements; all of which can be considered as fixed for the facility and the planned throughput.

We are convinced from our experience in planning manufacturing facilities that all these risks must be assessed and allowances made in the overall plan to compensate for their effect on production.

3.4 Risk Avoidance Factors

Typical of factors which must be considered in the decisions taken on the balance between extra costs and reduced risks are the requirements for:

- raw material inventory: increase the working capital by holding extra stocks of key materials to prevent stoppages from shortages
- quality control and testing: increase overheads and slow production throughput by introducing rigorous quality control systems including, non-destructive testing and dimensional checking with the aim of eliminating risk of rejections particularly in final assembly when they are most disruptive
- industrial relations: plan to avoid stoppages by introducing an enlightened and comprehensive working agreement free from restrictive practices; in particular ensure that all negotiations can be carried out with one body
- planned maintenance: increase costs by planning for regular checks and overhauls of plant and equipment; provide standbys to allow rotation of plant during overhaul
- duplication of facilities: avoid single element dependencies which could put output at risk if stopped
- work-in-progress (WIP) and buffer stocks: plan for storage of adequate WIP and buffer stocks to minimise risk of process stoppages which will reduce output
- absenteeism and holidays: plan for increased manning requirement to compensate for absenteeism, sickness and holiday allowances.

3.5 Location of Manufacturing

The manufacturing location is also of strategic importance with its effect on costs through three main influences:

Capital Grants

Financial incentives in the form of Regional Development Grants and other Selective Assistance through UK Government Agencies and the EEC can form a package worth up to 50 per cent of capital investment if the manufacturing is undertaken in specific areas of the UK. This significant benefit must be considered when costing alternative strategies and locations. The extent of the benefit is a political factor and fluctuates from time to time.

Productivity and Labour Rates

There are measurable differences between the productivity, industrial relations risks and wage rates in different areas of the UK and whilst this is a sensitive question it should not be ignored when considering large scale manufacturing facilities.

Materials and Towing

Material distribution has a lesser impact on costs than might initially appear. The balance between distribution costs of raw materials and tow out costs will probably favour a location which reduces the haul of raw materials. However, in the overall consideration of factors which will influence manufacturing location, transport costs are probably the least significant.

3.6 Business Approach

To summarise, we believe the concepts outlined above show a need for a business approach to the planning and costing for manufacture which will ensure that the benefits from efficient design and production are translated into a minimum manufactured cost for the devices. In addition to maintain minimum costs we believe there is a need to provide a competitive environment with cost targets, variance control and a profit motivation and to regard the manufacture of the devices as a commercial business.

4. DESIGN AND PRODUCTION CONCEPTS

We have already discussed in the context of the overall strategy the importance on costs of minimising risks and the impact of location. This section deals in more detail with the design and production concepts appropriate to a mass production approach to manufacture.

These concepts are:

- design the device for production
- provide bespoke manufacturing facilities
- mechanise and automate production.

4.1 Design for Production

The aim in applying a design for production philosophy is to develop a final device design which achieves the optimum solution between device efficiency and manufacturing cost. Inevitably a design which sets out to simplify the production process is unlikely to correspond with the ideal design for maximum operating efficiency. A 'trade off' must take place between these differing objectives to reach a compromise solution. This will be easier to achieve for devices with a simple rather than a complicated structural shape and the cost benefits will be greater.

Typically we aim for a design which is simple to construct, needing as few processes as possible with the maximum repetition. If this philosophy is applied in the design development of the device then considerable manufacturing savings can be made although probably at the expense of some increase in material costs. To illustrate the application of this philosophy we have extracted the following points from the A & P Appledore report of September 1979 commissioned by Wavepower Ltd which proposes a design for production approach to the Cockerell raft in steel plate.

- raft design is of simple 'box' shape with overall dimensions to suit a standard width of steel plate
- elimination of 'specials which require individual attention during the production process
- small inventory of basic materials comprising five different plates and five sizes of stiffeners
- wide use of common panels (plates with stiffeners at standard centres)
- common fabrication sequence for all sub-assemblies made from similar panels

- use of sacrificial steel to eliminate application of protective coatings which would extend and complicate the production process.

The effect of these design decisions is a raft which can be manufactured in a few stages. At each stage, the processes can be mechanised and automated to improve productivity and consistency of quality over labour intensive methods.

4.2 Provide Bespoke Facilities

In manufacturing terms the exciting prospect of the wave energy programme is the requirement for a facility to produce a single product on an ongoing basis for ten years or more. This is a tremendous opportunity to design a facility which incorporates all the advantages of a mass production approach and which optimises the use of resources.

A mass production approach usually features:

- manufacture split up into material receipt and initial processing, sub-assembly operations and final assembly

- assembly carried out on a flow line principal with the completed sub-assemblies fed in at the relevant point on the assembly line

- work stations dedicated to a set of prescribed tasks which are repeated on each product as it passes through the station

- tasks, manning levels, and production rates at each workstation are standardised and balanced to optimise the overall output

The extent to which these features are introduced when designing a factory depends on the flexibility needed in terms of product variety and the output required. If the factory is to make a single product then there can be a total commitment to designing layouts, feed lines, workstations, jigs, tools and equipment exactly to the requirements of that product. If however it is a multi-product factory the concept of a bespoke facility is less feasible.

In the context of the wave energy programme we see that there is maximum opportunity for planning a dedicated manufacturing facility for a single type of device. It must however have sufficient flexibility to be capable of adapting to suit product design changes.

It is possible to see how this approach can make greater use of mechanisation and automation in the manufacturing process.

4.3 Mechanisation and Automation

The benefits from automating the manufacturing process can lead to very significant improvements of the tasks performed through:

- greater productivity
- faster work rates
- consistent outputs
- consistent quality

These can in turn lead to a reduced production area due to the faster outputs.

The drawbacks are the need for:

- higher capital investment in plant and equipment
- more skilled maintenance personnel

In the UK we are still in the very early stages of development of automation and robotics in manufacture. At present only relatively simple tasks can be successfully automated and be cost effective. The next ten years will see robots developed which are more dexterous and cheaper than those in current use although there will always be many tasks which are too complex to be automated or need human decision making qualities.

Again the point we emphasise is that the product design which simplifies manufacture will allow greater use of automation in production with corresponding cost benefits.

4.4 Vertical Integration of Concepts

The concepts just discussed should be applied throughout the planning of the project and not just to the manufacturing process. For instance there might be scope at some material sources or in transportation to apply the same philosophy and so bring about a reduction in overall costs. Certainly the scale of this programme means that throughout, quantities and outputs are large and each 'link in the chain' warrants individual investigation with the aim of reducing costs. Consider two examples which illustrate this point.

- Steel plate for the Cockerell Raft

The quantities of steel plate required for a programme of rafts would warrant dedicating a medium sized rolling mill for the supply. If the requirements are standardised then the efficiency of such a mill would be improved and this should result in a reduction of the standard steel supply price.

- Rubber bags for the Lancaster Flexible Bag

The cost of producing bags by the proposed methods is very slow and labour intensive. Our initial investigations suggest that massive savings could be made if a new facility was set up solely to make these bags on a mass production basis using a more capital intensive approach and with the bags designed to simplify assembly to the structure.

5. REVIEW OF STEEL AND CONCRETE AS CONSTRUCTION MATERIALS

The Wave Energy Programme will create a unique demand for the ongoing manufacture of large structures, identical in shape and at a rate which obviously calls for a mass production approach. The ship building and construction industries traditionally operate on a 'one off' basis which is labour intensive although some mechanisation and automation has been introduced into certain processes. In the shipbuilding industry the lack of investment in mechanisation and automation has been due to inadequate demands to justify the expenditure rather than from lack of technology. A similar argument can be put for the construction industry although the problems with mechanising and automating concrete construction are more complex and stem from the need to cast materials in a mould. Benefits have however been obtained where repetitous demand occurs e.g. pipes, paving slabs.

In considering the comparative merits of steel and concrete as the main structural material for mass producing these devices we have not been concerned in our study with the fundamental design decisions on the choice of material for its physical properties and its suitability in a particular application. Indeed, each material may lead to the development of quite different designs for the same application. Our concern is the scope for reducing the manufacturing cost of the device in either material by introducing the mass production approach discussed earlier.

5.1 Steel

Steel has many properties which make it a suitable material for mass production manufacture:

- it is a 'clean' processed material of consistent quality which can be bought in a variety of sizes, thicknesses and pre-formed shapes which are easy to handle and store
- it is versatile and can be cut, formed and joined into complex shapes
- fabrication processes can be separated into tasks suitable for automation
- sub-assemblies can be readily manipulated and handled between processes without damage
- there is no 'curing' time to lengthen the manufacturing process

Its main drawbacks are:

- it is an expensive material
- scrap generated during fabrication can represent a significant cost
- welding can distort the assembly and create rejects

- in most applications it requires surface protection to prevent corrosion which increases manufacturing costs and creates a maintenance requirement.

The ongoing programme of research and development in steel creates further potential for improved welding techniques and anti corrosion properties.

Given the right approach to design and manufacture there is tremendous scope to reduce current 'one off' steel fabrication costs by introducing mass production techniques.

The benefits will come from a design which:

- reduces the number of operations e.g. preforming
- allows maximum raw material size
- uses common components
- reduces material inventory
- provides tolerances to reduce rejects
- reduces scrap

In addition steel allows improved productivity through automation of the various fabrication processes of:

- setting out
- cutting, preparing and welding
- manipulating and handling

5.2 Concrete

Reinforced concrete is a primitive and cheaper material compared to steel and much more limited in its possible application. The need to cast the raw materials and the interaction of the four main processes - steelfixing, shuttering, concreting, curing - makes construction difficult to mechanise and automate except on a limited scale.

The advantages of concrete as a material for mass production manufacture are:

- it is reasonably cheap
- complex shapes can be formed in a mould and repeated accurately
- semi-skilled labour can be used
- it is durable and requires no surface protection
- there is a low waste factor in normal manufacture
- materials are readily available.

The drawbacks are:

- it is not a processed material
- it is a 'dirty' abrasive material which shortens the life of associated factory plant
- products are heavy and expensive to handle
- the need for curing extends the manufacturing time
- quality control is needed to ensure consistency
- rejects cannot be recycled and disposal is expensive
- it is expensive to implement changes in shape
- sub-assemblies are difficult to join together.

Precast factories have introduced mass production techniques and dramatically reduced the cycle time and costs by:

- automating the prefabrication of reinforcement cages
- automating shutter fixing and striking
- mechanising the delivery and placing of concrete
- accelerating the concrete curing time
- providing covered facilities to reduce the weather risk.

However, the penetration of mass production into the concrete industry is limited to products of simple shape which can be easily handled.

For large structures such as the wave energy devices the scope for introducing mass production techniques such as the above in order to reduce costs will depend on the extent to which precasting can be introduced. The benefits will come from a reduction in the labour intensive activities of steel fixing and shuttering and a shortening of the construction programme due to accelerated curing and concurrent casting and assembly operations.

The problem with this approach for large structures is the technical difficulties and cost in jointing units which erode the benefits gained by precasting. Also this approach is more readily introduced in certain structural shapes than others and this is a limitation on its universal application. This point is discussed later in Section 6 on the individual devices.

To summarise, we believe that manufacturing in concrete will provide less scope than steel for reducing costs through a mass production approach.

However, the overall cost of manufacturing each device in steel or concrete will depend on many other factors, particularly its mass, and only by detailed investigation of each case can an accurate estimate of total cost be made.

6. EXAMINATION OF MANUFACTURING COSTS

This section summarises our investigation into the manufacturing costs of the three devices using steel and reinforced concrete as the prime materials. All costs are based on 1979 prices without allowance for inflation. The extent of the investigation has been limited by the availability of design details. The table below shows the current position on conceptual design data available to us for the three devices in the two prime materials.

	Steel	Concrete	
Cockerell Raft	A	A	
Lancaster Flexible Bag	NA	A	
Salter Duck			
Spine	NA	A	A = available
Body	A	A	NA = not available

Within this matrix, the amount of detailed data available on each device varies significantly since each is at a different stage of development. This has led us to concentrate on those devices which offered the greatest scope for analysis. However, none of the devices are developed to a detailed design stage when accurate estimates can be made of manufacturing costs and so our comments are necessarily aimed at the overall effect on costs of certain concepts and decisions. These are relevant to all the devices to a greater or lesser degree. We will indicate for each device our view of the minimum manufacturing cost obtainable based on current designs and qualify our figures with comments.

We have used the elements of the cost model described in Section 3 as the main headings under which to review the costs, and most of the general comments will apply to all devices.

6.1 Comments on Materials

We have outlined earlier in this report how the design for production can have an influence on the material cost of a device. Once a design has been finalised the material content is fixed and the opportunity to reduce costs lies solely with the methods of processing and supply.

These can be summarised as:

- economies of scale
- long term contracts
- dedicated sources of supply
- location of sources of supply
- investment at sources of supply to reduce unit costs

Consider the following materials which are common to all three devices and the factors which will influence their price.

6.1.1 Concrete Designs

Cement - the cement industry operates a fixed pricing policy which sets an ex-works price. In England the price is currently £29.19 per tonne for OPC and from the only plant in Scotland at Dunbar £30.47 per tonne. These prices are for a 15 tonne bulk load and transport is charged at a rate of £0.22 per tonne per five mile radius. There is adequate spare capacity in the UK to meet the heaviest planned demand of some 180,000 tonnes p.a. for Raft manufacture and on current policy an order of this size would not attract any discount. To give an example of how location would affect the cement price a haul of 100 miles would add between £3 per tonne by rail and £4.5 per tonne by road.

Concrete additives particularly plastisizers are being considered by the device teams. Such chemicals are added as a percentage of the cement content and should be considered in the price of the cement. Costs will vary with dosage but could add between £5 and £10 to a tonne of cement. The cost of cement at the production site could therefore vary in the range £35-45 per tonne but we believe the cost is likely to be closer to the higher figure.

Aggregates - large quantities of aggregates will be needed to supply a facility producing concrete devices. A Raft facility would require 800,000 tonnes each year but this can be put in perspective when considered against a total UK output in 1977 of 192 million tonnes. The following table indicates typical bulk production costs of aggregates:

	£ per tonne
Land won sand and gravel	1.30
Marine dredged sand and gravel	1.90
Crushed limestone	1.30
Crushed hardstone	2.40

The handling and transport costs will account for a significant part of the on site cost and for large quantities a rail or sea link is essential. Costs of £2 per tonne per 100 mile haul are typical. Although a considerable logistical problem, the transport of aggregates over large distances will not significantly affect the cost of concrete which is much more sensitive to the cement price and content.

Reinforcing Steel - there is little scope for attacking the cost of bar reinforcement. The steel industry has plenty of spare capacity and the quantities involved do not provide opportunities for any great economies of scale. Given that the steel could be delivered in standard lengths or in bulk coils then a likely cost is £200 per tonne. The transport element represents about five percent of this cost and could be by rail or road.

Prestressing Steel - all the devices under review require prestress by post tensioning methods and this means that other materials have to be included in the costs. These include:

- strand
- duct
- anchorages and couplers
- grout.

The length and size of cables will be determined by design requirements and methods of production. Short cables involve more anchorages per tonne of strand and more wastage and this can significantly effect the total costs. Our estimates of the material cost per tonne of strand vary between £650 and £800 for the different devices of which the strand alone represents some £500 per tonne.

The annual demand of strand for Rafts is 32,000 tonnes and represents about 30 per cent of current UK output. However this very significant order would be unlikely to reduce UK manufacturing cost much below £500 per tonne. The effect of such a demand is more likely to stabilise the prices over a period of years since it would help to flatten the peaks and troughs in demand which the industry has traditionally faced. This might seem a conservative statement since it is currently possible to buy imported Japanese strand at a spot price as low as £400 per tonne. This is due to the worldwide over capacity for strand manufacture. However it is very unlikely that any source would be prepared to supply a large long term contract at this marginal cost price since it does not reflect the true commercial cost of manufacture.

6.1.2 Steel Designs

Steel plate and rolled sections - discussions with BSC suggest the price of the steel would be negotiable and vary between £184-225 per tonne depending on the variety, size and quantities required. The low price is for steel plate as quoted in the Appledore report and could be achieved for the following reasons:

- plates would all be the same width in only two thicknesses
- the quantity required for a raft factory is sufficient to dedicate the production from one rolling mill which can be programmed on a continuous basis with greatly improved efficiency and less waste
- plate thicknesses specified are 14mm and 18mm which require less rolling time than thinner plates with corresponding improvements in productivity.

Welding Electrodes - an allowance of some two per cent by weight is typical for welding electrodes on large fabricated structures. The material cost of welding can vary significantly with the composition of the rods but for current technology in mild steel a bulk supply cost of £650 per tonne is estimated.

6.1.3 Sundries

This heading is deliberately unspecific since at this stage of design it is impossible to establish a meaningful material list. We think an allowance of five per cent is not unreasonable to cover such items as:

- jointing compounds (resin and cement mortars or grouts)
- water bars/seals
- inserts/fasteners
- all other prime materials

6.2 Material Costs

In Appendix 1 we have summarised the material content of each device and our unit costings for each material. The following table compares the material costs per tonne displacement for each device and gives an indication of how different designs and shapes can alter the cost of similar materials.

Table 6.2 Material Cost per tonne displacement

	£ per tonne RAFT	BAG	DUCK Spine	DUCK Body (excl beak)
Concrete				
Cement	7.6	7.8	6.9	14.5
Aggregates	3.0	3.1	3.1	7.7
Reinforcement	8.5	7.5	8.5	12.6
Prestressing	24.0	7.0	20.5	8.6
Sundries	2.1	1.3	2.0	2.2
TOTAL	45.2	26.7	41.0	45.6
Steel				
Steel plate	186			178
Electrodes	13			11
Steel pipes	--			49
Sundries	10			12
TOTAL	209			250 (excl surface treatment of the steel)

6.2.1 Cockerell Raft

The design in concrete makes extensive use of prestressing materials to join together precast sub-assembly blocks. Stressing is required in both the longitudinal and transverse directions and this results in a high prestressing material content per tonne displacement. The consequences on cost are very significant and are highlighted by the comparison with the Bag.

In contrast the work done by A & P Appledore has reduced the cost per tonne of steel plate by quantity and standardisation discounts and they have also avoided the cost of surface protection by increasing the thickness of steel plate with further benefits to the unit steel cost. However, the increased steel quantity will reflect in the overall cost of the device.

6.2.2 Lancaster Flexible Bag

The consistent cross section of this device makes it a suitable design for economic manufacture in concrete and the beam shape allows for stressing to be confined to the longitudinal direction resulting in significantly lower material costs per tonne displacement compared with the other devices.

The figures in Table 6.2 do not include for the rubber bags which can be considered as a material supply item for the structure rather than for the power generation equipment. Our discussions with a leading company in the rubber industry have indicated that a potential manufactured cost of £200,000 per device could be achieved if a dedicated factory was established. This would result in an additional material cost which would then be:

	Bag
Concrete	26.7
Rubber Bags	18.9
TOTAL	£45.6

No design exists for the Bag in steel. We believe the same design approach as for the Raft could be applied to this device and that the overall steel cost would be very similar at approximately £210 per tonne. The major forseeable problem for a steel design is the need for excessive ballasting for the 'in service' condition and the possible adverse effect on steel quantities.

6.2.3 Salter Duck

Most effort has been put into a design for the spine in concrete and the Duck body in lightweight concrete. The material costs for the spine, shown in Table 6.2, are similar to the Raft and again indicate a high proportion of stressing material per tonne although the stressing requirement is unidirectional. The Duck body is the most complex structure of the three devices and with a standard concrete design there are flotation problems. The current design uses lightweight concrete to overcome this problem but the result is a high cement content which significantly increases the material cost. The complex shape also requires some stressing in two directions and an increased reinforcement content which all contribute to give the body the highest material cost per tonne displacement.

The only steel design is for the Duck body and again the complex shape will adversely effect the steel price. The shape and current design makes it very difficult to standardise on plate and pipe sizes and also to avoid a high wastage factor. The cost in Table 6.2 makes no allowance for external surface treatment to the steel which will further increase material costs and significantly increase production costs. A sacrificial steel solution might be more cost effective in the long term and should be considered as an alternative to surface treatment.

6.3 Labour and Productivity

A mass production approach to manufacturing these devices must aim to reduce the labour cost significantly if any overall savings are to be achieved.

For either steel or concrete construction the current average labour rate can be taken as £4 per hour and the labour cost can be considered directly in terms of productivity, expressed in man hours per tonne. Traditional 'one off' construction in the shipbuilding and concrete industries give widely varying productivity figures which can be related to the size and complexity of the structure, as illustrated in the following table.

Table 6.3 Examples of Labour Productivity (man hours per tonne)

Concrete		Steel	
Insitu construction of large, heavily prestressed structure of simple shape	14	'One off' shipyard construction	100+
Mass production of precast concrete products (1-3 tonne)	2	Series production of large tankers in Sweden (steel fabrication only)	12-15
Insitu construction of large complex structure	30+		

6.3.1 Concrete Construction

The simple shapes of the Raft and Bag allow a method of construction using common sub-assemblies with very few complex specials. If constructed insitu on a 'one off' basis we believe a target productivity level of 14 man hours per tonne could be achieved. A more detailed consideration of the shuttering and steelfixing operations for a mass production approach suggest that there is potential to reduce the target to

8 man hours per tonne. The Duck is more complex and does not offer the same potential; in particular the steelfixing cages cannot readily be prefabricated using continuous matt welding techniques and there is a high prestressing content. We would expect a productivity level closer to 12 man hours per tonne for the Duck.

Taking these figures, the manning levels to achieve the annual requirement would be broadly:

	Raft	Bag	Duck
Labour Manning	4,100	1,350	1,300

The manning figures assume an average 45 hour week, 45 weeks a year which allows for absenteeism and holidays.

Assuming a three shift operation and including management there could be 600-700 people on site for a facility to make the Bag and Duck which is about the maximum size we would recommend as a manageable unit. A single Raft facility would need 1,500-1,700 people per shift and the manufacturing risks would be much greater and suggest multi-location production. However, a decision to manufacture the Raft in two or three locations would increase unit costs through increases in:

- capital expenditure
- financing charges
- overheads

6.3.2 Steel Construction

The greater potential for increased productivity lies with the Raft and Bag rather than the Duck. The A & P Appledore study, on a steel Raft proposes a manning level equivalent to a productivity of 5-6 man hours per tonne from a highly mechanised and automated factory. This is a very low figure when compared with the best rates achieved in the shipbuilding industry for the series production of tankers and bulk carriers. However that is not a valid argument and we think this sort of figure should represent the target that could be achieved if a cost effective approach is taken to the design of the device, the production facility and the organisation and management of the whole manufacturing programme.

The important point about a capital intensive approach to manufacture is that the total cost is relatively insensitive to the direct manning levels and more sensitive to the effect on production of the 'cost risks' outlined in Section 3. This is further commented upon in Section 7.1.

The shape of the Bag would allow the same approach to manufacture as the Raft and it would be reasonable to assume a similar level of productivity.

The Duck is more complex and unlike the Raft and Bag cannot be made using large quantities of common panel blocks; also there is a greater requirement for cutting and shaping the steel plate which is wasteful of material and time consuming. A mass production approach to manufacture is still relevant but without the same scope for mechanising and automating the processes. The productivity will be lower and we would suggest 15-20 man hours per tonne is a more realistic target.

6.4 Capital

The capital investment can be considered as the total expenditure over the life of the facility on:

- civil engineering
- buildings and services
- plant and equipment

The costings are based on the equivalent of a two gigawatt power station to be produced in ten years. Allowing for plant replacements the total capital costs are then amortised to give an apportioned capital charge per device. This does not take into account the residual value of the assets at the end of the period and is therefore a conservative figure but it does represent the real cost for budgeting purposes at the time that a decision is made to commit the expenditure. The residual value of the assets can be reflected in the costings should a decision be made to extend production beyond the ten year programme.

At this stage, it is only possible to produce 'order of cost' figures for the capital expenditure. Civil engineering costs could vary widely depending on whether a greenfield location was chosen or an existing facility was converted. The buildings costs are more predictable and assuming covered facilities throughout we do not think there will be a significant difference in the costs for steel or concrete devices. Estimating the total expenditure on plant and equipment is also very difficult and can only be based on a rough costing of the major items of plant which will be required.

The following table summarises our thoughts on capital expenditure for the three devices. (The impact on overall costing of these figures is shown in the series of tables in Appendix 2).

Table 6.4 Estimates of Capital Expenditure
£ millions (excluding grants)

	Raft Steel	Raft Concrete	Bag Concrete	Duck Concrete
Civil Engineering	20	20	25	15
Buildings and Services	40	50	36	30
Plant and Equipment	20	30	24	23
	80	100	85	68
Contingency	20	25	20	17
	100	125	100	85

All the figures represent a significant investment but because of the scale of the programme the manufacturing cost of the devices is relatively insensitive to the initial capital expenditure. It is only when the financing charges are added that the costs become significant. This point is expanded in Section 7 on Sensitivity of Costs.

6.5 Overheads

Costs vary according to the type of industry and method of manufacturing. For mass production industries with a heavy capital investment we would expect overhead costs excluding sales and distribution to amount to 15-20 per cent of the material and labour elements.

The lower figure of 15 per cent has been used in the tables in Appendix 2 as we think this is a reasonable target for mass production on this scale. However we must emphasise that this cost more than any other is a reflection of the 'management' of manufacture and the soundness of decisions taken in the strategic planning of the facility when production methods, manning levels, operating systems and throughput are set. Inefficient and uncompetitive manufacturing facilities can normally be associated with high overhead costs.

6.6 Commercial

The commercial elements of cost include financing charges which are directly related to capital employed and also profit which is normally a combination of returns on capital and turnover.

To illustrate the significance of the commercial costs on the devices and the impact of grant aid we have shown in Appendix 2 an example of a facility manufacturing steel rafts located in an area of maximum financial assistance with one receiving no financial assistance.

A current interest rate of 16 per cent has been used in these calculations.

To illustrate the effect of a lower figure which will hopefully apply at the time the project proceeds we have also shown a total commercial cost based on an interest rate of 10 per cent.

The following table is a summary of the Commercial Costs.

Table 6.6 Commercial Costs of Raft Manufactured in Steel

	No assistance	Maximum assistance including ECSC* loans
Financing charge per tonne	£ 28.4	£ 19.2
Profit		
Should a return of 4 per cent on turnover be required (equivalent to a return on capital employed of 8.2% or 10.1% with assistance) then the cost per tonne would increase by:	£ 14.1	£ 13.7
Total commercial cost: (16% interest rate)	£ 42.5	£ 32.9
Alternatively at 10% interest rate	£ 31.9	£ 21.4
Similar calculations for a facility making 80 concrete rafts with an annual output of 1,040,000 tonnes would give total commercial costs per tonne of: (16% interest rate)	£ 17.0	£ 12.1

* European Coal and Steel Community.

6.7 Cost Summary

To summarise the results of our investigations discussed earlier in this section we have produced in Appendix 3 a table of indicative manufacturing costs for the three devices.

An extract from this Appendix is given below:

Table 6.7 Manufacturing Costs (£ per tonne)

	RAFT Steel	RAFT Concrete	BAG Concrete	DUCK Concrete
Material	209	45	46	43
Labour	40	32	32	48
Capital (note 1)	18	8	21	27
Overheads	36	11	12	14
Commercial (note 2)	33	12	21	26
TOTAL	336	108	132	158

7. SENSITIVITY OF MANUFACTURING COSTS AND COMMENTS ON RISK ALLOWANCES

In Appendix 4 we have produced a series of tables showing the manufacturing costs of the Raft in steel and concrete. We have chosen the Raft to illustrate these points because it is the most developed device for our purposes with conceptual designs in both steel and concrete.

The tables show the impact on total cost of substantial increases in:

- labour cost
- capital expenditure

and also the effect on profitability of a failure to meet planned output.

7.1 Labour Costs

The example in Appendix 4 increases the labour cost by 50 per cent and results in the total costs being increased by 7 per cent for the steel raft and 18 per cent for the concrete raft. This difference is a reflection of the greater labour content involved in the concrete manufacture. However such an increase in labour cost for concrete would imply manning levels close to an insitu approach to construction when a less capitally intensive model would be appropriate.

7.2 Capital Costs

The second example in Appendix 4 increases the capital expenditure by 50 per cent and this increases the total costs for the steel raft by 4.7 per cent and for the concrete raft by 6.5 per cent. Considering that the cost model represents a capitally intensive approach to manufacture the total cost is not very sensitive to a £50-65 million increase in capital expenditure. Also these figures are based on the current very onerous interest rates of 16 per cent per annum. Lower interest rates will reduce the financing charges and hence the total costs making the model even less sensitive.

Both examples are included to show the sensitivity of the model to decisions to commit extra capital expenditure or increase manning levels or labour rates.

7.3 Loss of Output

During manufacture the importance of the risks outlined in Section 3.3 and 3.4 can be shown as their effect on profitability resulting from a loss of output.

The cost risks can occur randomly at any stage in production and reduce the efficiency of that process. The impact locally is far less significant than the disruption of production that can occur as these incidents accumulate. The consequences of a loss of output are certainly significant as the third table in Appendix 2 shows.

A 25 per cent loss of output increases the unit cost of the steel raft by 8 per cent and the concrete raft by 17 per cent. Since our cost model is based on a profit margin of 4 per cent on turnover this reduced output would create manufacturing losses of some 4 per cent for the steel raft and 13 per cent for the concrete.

These tables illustrate an important point which is fundamental to mass production manufacture. In planning and designing a facility for a given output, adequate allowances must be built into each operation to compensate for the effect of the random variancies in output which we have outlined in Section 3.3.

The result will be to raise the cost of the device by increasing the budgeted labour, capital, overhead and commercial costs by the risk allowances. If the allowances are not adequate and the facility fails to meet the planned output then the costs will be increased and the devices will be made at a loss.

7.4 Risk Allowances and Sensitivity

To illustrate the concept of sensitivity we have produced a table in Appendix 5 showing the effect of risk allowances on the estimated costs for a steel Raft. The figures are not based on any quantitative analysis but represent our view of the sort of allowances which could be appropriate. The table shows that for the steel Raft the costs could be increased by up to 11 per cent. Similar consideration of the concrete Raft would probably produce a higher figure, the difference being largely a reflection of the more complex interrelation of the operations in the concreting cycle which increases the risk of unproductive time.

We think it is unlikely that the effect of these excesses would be outside a 5-15 per cent range for any of the devices but this is of course very significant for a cost model with only a 4 per cent profit margin. However manufacture is on such a scale that a few per cent on turnover represents a very large profit and for this reason there will be pressure to operate on a low margin on turnover if it gives an adequate return on capital employed. This can only be done if most of the foreseeable risks are accounted for in the costings and the profit margin reflects an acceptable level of risk. In our view this would imply an increase in the estimated cost for the steel Raft of perhaps 10 per cent.

In Appendix 3 we have produced a table of estimated device costs. At the bottom of the table we have added a 5-15 per cent risk allowance to account for the impact of excesses over budgeted manufacturing costs. These figures can only be indicative and should not be taken as accurate assessments. We have included them to highlight the effect of the important concept of risks and margins which should be considered whenever setting up a production operation with multi-dependent processes.

8. REVIEW OF MASS PRODUCTION BENEFITS

In the context of our investigations, mass production is relevant where a long term programme is planned to make the same device on a repetitive basis. Such a long term programme encourages the investigation of greater manufacturing economy through more capital expenditure on specialist plant and equipment, including automation, since the additional costs can be spread over many units.

The main reasons for expenditure on additional plant are to:

- create cost benefits by offsetting the amortisation of higher capital costs against a greater reduction in labour costs
- improve quality by automated consistency again with cost benefits in rectification and rejects
- increase output above the limiting resource usually of labour or skill availability
- reduce risks and increase reliability again with cost benefits.

Our investigation shows that mass production in steel can significantly reduce costs compared with a traditional 'one off' fabrication cost. Using the Raft design the target we would suggest is a mass production cost of around £370 per tonne compared with £600+ per tonne by traditional methods. It is also possible to envisage all production being carried out at one large facility with a total direct work force of under 2,000 people resulting in benefits in management, technical staff and launching.

These savings can only be achieved in steel if a number of key factors are met; including:

- the design sets out to simplify manufacture including standardisation of materials and production operations
- most fabrication processes are automated
- surface protection of the steel is not required
- the facility is designed specifically for production of a known device.

We believe the same comments can be applied to a Bag made in steel but there will be problems in satisfying the first three requirements with a steel Duck design.

We cannot see that there is the same scope for reducing the cost of a concrete device by introducing mass production techniques. Again taking the Raft as an example our estimates suggest a mass production cost of £120 per tonne. This is not an appreciable saving on current 'insitu' construction costs in concrete which typically range from £120 to £160 per tonne.

In order to obtain benefits from mass production in concrete it will be necessary to automate the activities which points to the need to precast in a specifically designed yard. The problem with the Raft is then the need to joint large sub-assemblies. These have to be post tensioned in two directions and this significantly increases the prestressing and material costs and removes most of the cost advantages gained by precasting the sub-assemblies. The alternative of insitu construction of the current design although slower and more labour intensive would allow more efficient and cheaper use of materials and hence generate cost benefits to offset against the higher labour costs.

If mass production does not provide a cost advantage then a multi-site insitu strategy is more attractive since it spreads the risk of lost output and allows the workforces to be kept to manageable levels. A single facility mass producing Rafts would require some 5,000 personnel and this represents a bigger risk of disruption and loss of output with correspondingly adverse effects on cost.

Similar arguments apply to the Bag although its "beamlike" shape allows jointing and stressing to be confined to one direction and this reduces the problem.

Even so, a traditional approach with investment in purpose made shutters designed for a rapid turnround and automation of the steel reinforcement prefabrication could provide very efficient insitu construction without any of the investment in handling and jointing that a precasting approach requires.

If handling costs are high there is a strong argument against pursuing a method of production which increases the handling requirements.

To summarise, we believe a mass production approach to the manufacture of large concrete structures will not produce the same benefits as for steel because of the complicated construction process and the extra costs of handling large heavy sub-assemblies. These erode the benefits gained from improving the efficiency of the concreting cycle by automating the precasting process.

Possibly the greatest potential for concrete would be a design and manufacturing method which minimise the need for costly jointing and post tensioning operations. A design for production approach to concrete which would simplify construction insitu would seem to be the objective requiring further work if significant mass production benefits are to be obtained.

9. CONCLUSION

The objective of this report is to express opinions on the order of possible costs obtainable by adopting a mass production approach to the construction of wave energy devices. From our investigations we believe the following points need to be emphasised.

- it is important to understand how a "cost" is derived and the relationship of the various elements within the total

- the designs will have to reconcile the best shape for energy absorption with less efficient but cheaper designs for production

- ultimately the structural cost of a device is the product of two elements:

  - the mass in tonnes

  - the manufacturing cost in £ per tonne

  The design development must aim to optimise this product to achieve the minimum cost.

- the eventual choice of the best device and material will need to consider all the factors in total cost. From the manufacturing point of view the key ratio which needs to be monitored is of course the cost/kw. For a device in a particular material this ratio is derived from the mass/output (tonnes/kw) and the cost/tonne (£/tonne)

- strategic planning will be required of both the manufacturing methods and facilities to suit the device design, again with particular attention to cost minimisation

- risk assessment should be included to see the effect of variances with the aim of reducing possible excesses

- cost reduction studies will be required during the detail design development stage and will be most successful if 'value analysis' type methods are used and emphasis placed on an iterative approach attacking the cost of all elements until a minimum figure is reached. As an example, prestressing materials make up half the material cost of the concrete Raft and are therefore a suitable target for cost reduction. This comment is relevant to all sections of the wave energy programme since the goal must be to find the minimum cost of power generation.

When design and manufacturing methods can be reconciled, then significant savings in mass production costs in steel are possible. The concrete designs appear to have a reduced potential because of their size and jointing problems.

We suggest that attention to manufacturing and launch out cost should be an ongoing activity once the conceptual design has been resolved. This should clarify design development programmes and by imposing disciplines prevent abortive development of non-productive ideas.

Submitted for The P-E Consulting Group
by

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MATERIALS - QUANTITIES AND COST DATA FOR THE THREE DEVICES

Concrete Quantities in Tonnes	Cockerell Raft (CR)	Lancaster Flexible Bag (LFB)	Salter Duck (SD) (see note 1) 1 spine	2 bodies
Displacement (approximate)	13,000	10,600	3,000	1,300
Cement	2,200	1,830	460	420
Aggregates	9,850	8,240	2,320	340
Lightweight Aggregates				470
Reinforcement	550	400	127	82
Prestressing	400	120	77	14
Steel Quantities in Tonnes				(see note 2)
Displacement (approximate)	5,000	--	--	470
Steel plate	4,900			400
Electrodes	100			8
Steel pipes				62

Material Costs		£ per tonne
Cement		45
Aggregates		4
Lightweight Aggregates		20
Reinforcement		200
Prestressing	CR	780
	LB	620
	SD	800
Steel plate	CR	190
	SD	210
Electrodes		650
Steel pipes		370

Notes:

1. Weight of duck body excludes the beak, pressure vessel and mechanical equipment which is taken as a power generation supply item.
2. Includes a 10 per cent scrap allowance.

EXAMPLE OF COMMERCIAL COSTS - STEEL RAFT

Raft Manufactured in Steel by an Enterprise with AI credit rating (underwritten by Government)

	No assistance £000's	Maximum assistance including ECSC* loans £000's
Capital cost on fixed assets	100,000	100,000
Less Grants	---	30,000
Net Capital cost	100,000	70,000
Working Capital - 2 mths. manufacture	21,000	20,000
Financing Charges Per Year		
Average interest @ 16% per annum of fixed assets borrowing requirement over 10 year period	8,000	1,600
Average interest on ECSC loan @ 10.25% of half fixed assets borrowing requirement		2,888
Interest @ 16% per annum on loan for Working Capital	3,360	3,200
	11,360	7,688
Planned output per year: 80 steel rafts 400,000 tonnes		
Financing charge per tonne	£ 28.4	£ 19.2
Profit		
Should a return of 4 per cent on turnover be required (equivalent to a return on capital employed of 8.2% or 10.1% with assistance) then the cost per tonne would increase by:	£ 14.1	£ 13.7
Total commercial cost:	£ 42.5	£ 32.9
Alternatively the total commercial cost for an annual output of 80 steel rafts with a 10 per cent interest rate would be	£ 31.9	£ 21.4
Similar calculations for a facility making 80 concrete rafts with an annual output of 1,040,000 tonnes would give total commercial costs per tonne of: (Interest @ 16% per annum)	£ 17.0	£ 12.1

* European Coal and Steel Community

APPENDIX 3

PE

ESTIMATED DEVICE COSTS

	RAFT Steel	RAFT Concrete	BAG Concrete	DUCK Concrete
Displacement weight (tonnes)	5,000	13,000	10,600	4,300
Capital - Assets £m	100	125	100	85
- Working £m	20	15	6	5
MANUFACTURING COSTS (£ per tonne)				
Material	209	45	46	43
Labour	40	32	32	48
Capital (note 1)	18	8	21	27
Overheads	36	11	12	14
Commercial (note 2)	33	12	21	26
TOTAL	336	108	132	158
Add Risk Allowance 5-15 per cent	353-386	113-124	139-152	166-182
SUMMARY				
Device Cost £ millions	1.77-1.93	1.47-1.61	1.47-1.61	0.71-0.78
No of Devices for 2 Gigawatt (note 3)	800	800	320	510
kW/tonne	0.50	0.192	0.588	0.912
2 Gigawatt Cost £ millions	1416-1544	1176-1288	470-515	362-398
Structure cost/kW (£ per kW)	706-772	588-645	236-258	182-199
COMMENT			**Includes Rubber bags**	**Excludes Spine joints Duck beaks Power generation pod**

Notes:

1. Includes grant aid
2. Includes interest and profit
3. Figures cement during the study but subsequently revised.

SENSITIVITY OF MANUFACTURING COSTS

The following tables illustrate the sensitivity of overall costs to changes in the labour, capital, and risk (expressed as a loss of output). We have used the cost models for the Raft in steel and concrete.

The standard model for a steel Raft is a facility costing £100 million and with a productivity of 10 man hours per tonne. The concrete raft is made in a facility costing £125 million and with a productivity of 8 man hours per tonne. Both facilities located to gain maximum financial assistance.

	Steel		Concrete	
	£/tonne	%	£/tonne	%
Materials	209	62	45	42
Labour	40	12	32	30
Capital	18	5	8	7
Overheads	36	11	11	10
Commercial	33	10	12	11
	336	100	108	100

Labour

Manning levels (single shift) 1,780 4,100

Assumption 1 - Increase labour costs by 50 per cent

Materials	209	58	45	36
Labour	60	17	48	38
Capital	18	5	8	6
Overheads	40	11	14	11
Commercial	33	9	12	9
	360	100	127	100
Increase in unit cost	7%		18%	

Capital

Assumption 2 - Increase capital requirement by 50 per cent

Materials	209	60	45	39
Labour	40	11	32	28
Capital	27	8	12	10
Overheads	36	10	11	10
Commercial	40	11	15	13
	352	100	115	100
Increase in unit cost	4.7%		6.5%	

Risk

Failure to meet output by 25%
Produce only 60 units instead of 80 in one year.

Materials	209	57	45	36
Labour	53	14	43	34
Capital	24	7	11	9
Overheads	38	11	12	9
Commercial	40	11	15	12
	364	100	126	100

Increase in unit cost	8%	17%

EXAMPLE OF RISK ALLOWANCE
STEEL RAFT MANUFACTURE

Excesses	Comment	Esti mated % Note 1	Risk sensitivity % Note 2	Comment	Variation in total cost % Note 3
Waste materials	Unavoidable scrap	3	0 to 5	Increased scrap	0 to 3.1
Rejected parts		none	0.5	Scrap due to rejects.	0.3
Stoppages of:					
Labour	Unproductive time - included in productivity levels		up to 25	Excess unproductive time due to random bottlenecks etc,	0 to 3.5
	Industrial action	none	up to 2	Loss of output due to industrial action	0 to 0.5
Plant	Breakdowns	none	up to 0.5	Loss of output due to breakdowns	
	Under utilisation - allowance included in production plan		up to 25	Excesses due to random bottlenecks	0 to 2.4
Shortages of:					
Material	Planned stock levels taken as two months		0 to 1	Increased material cost due to larger inventory	0 to 0.7
Labour	Absenteeism, sickness	4	0 to 6	Absenteeism can be 10% in some factories	0 to 0.8
				TOTAL	**0 to 11.3**

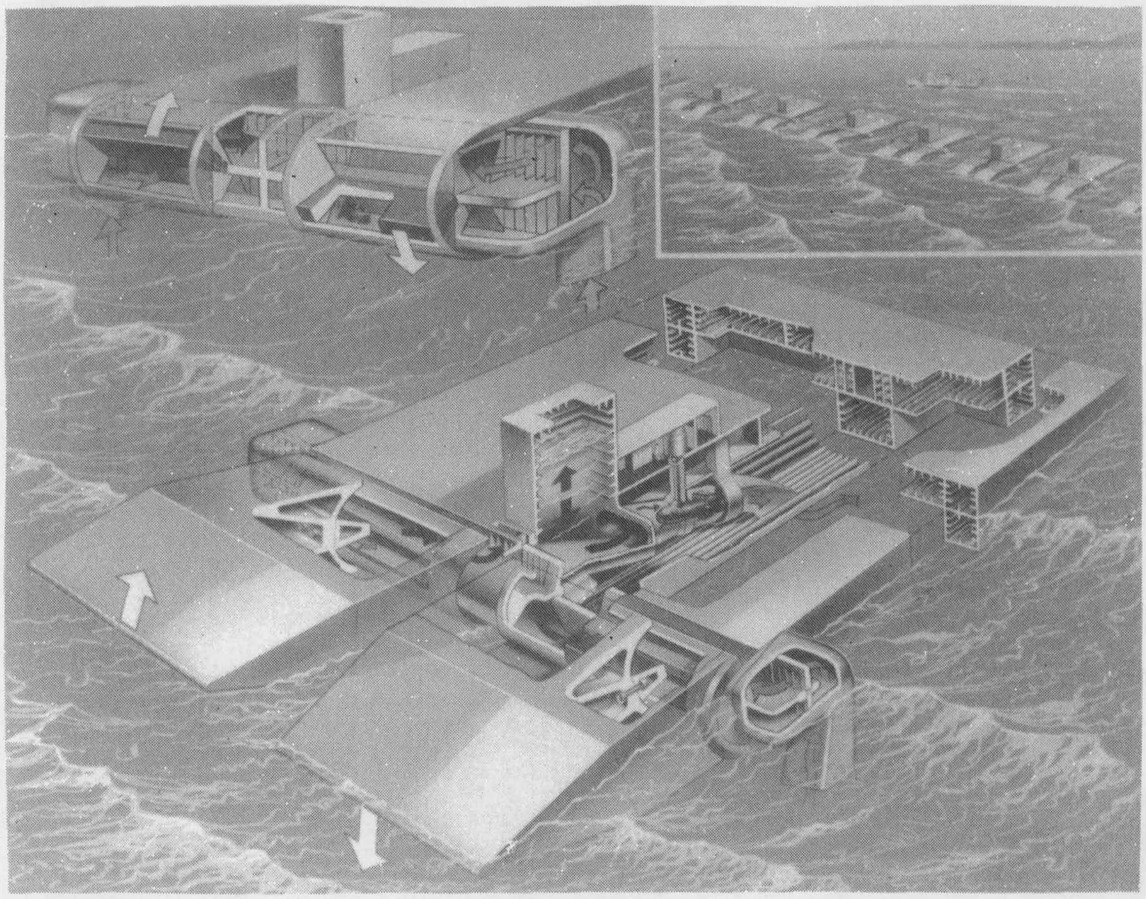
Notes:

1) This amount has been included in the estimates

2) This is a possible range of percentages which could run

3) A weighted figure of the sensitivity percentage in relation to the elemental and total cost.

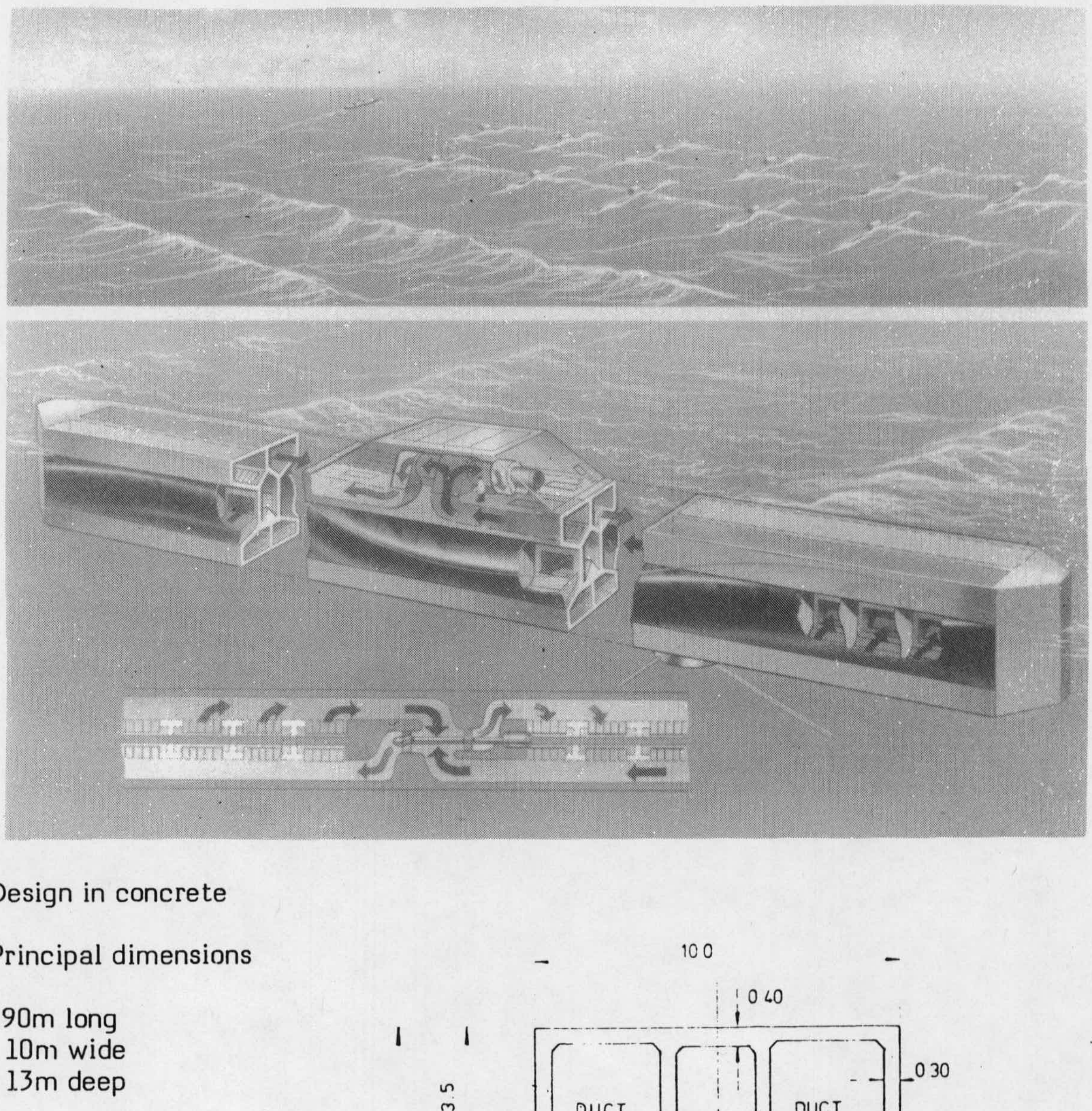
COCKERELL RAFT (Low Pressure)



Design in steel plate

Principal dimensions

Back Raft	68m long	48m wide	8m deep
Flaps	32m long	18m wide	

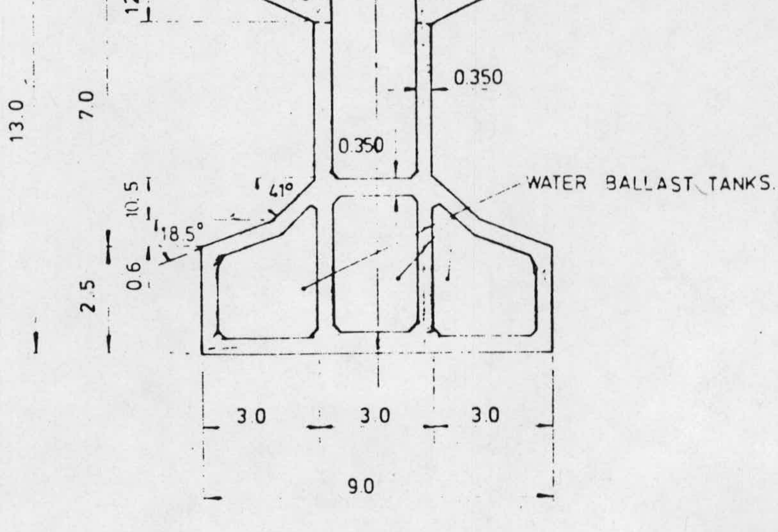


Design in concrete

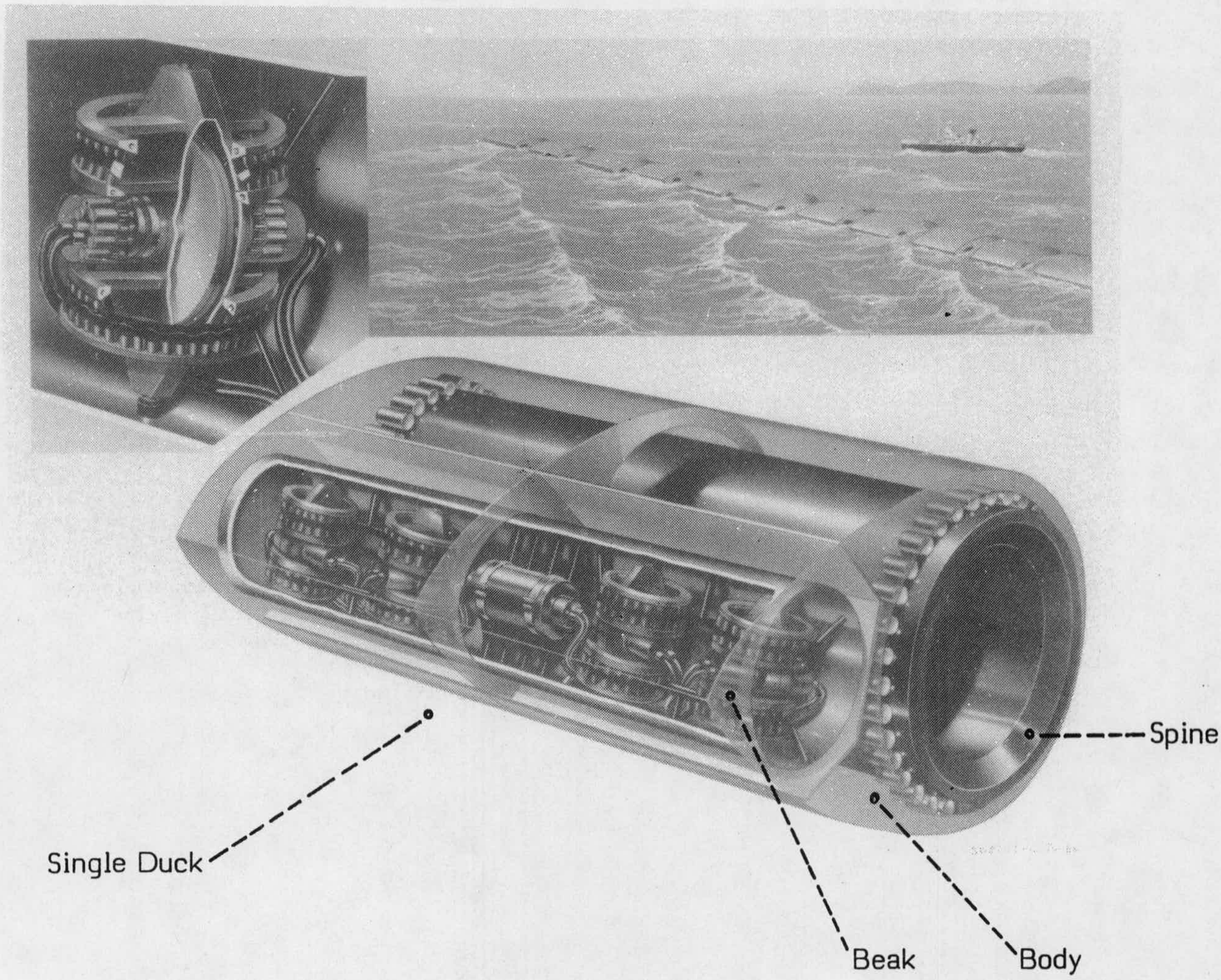
Principal dimensions

190m long
10m wide
13m deep

Typical Cross Section

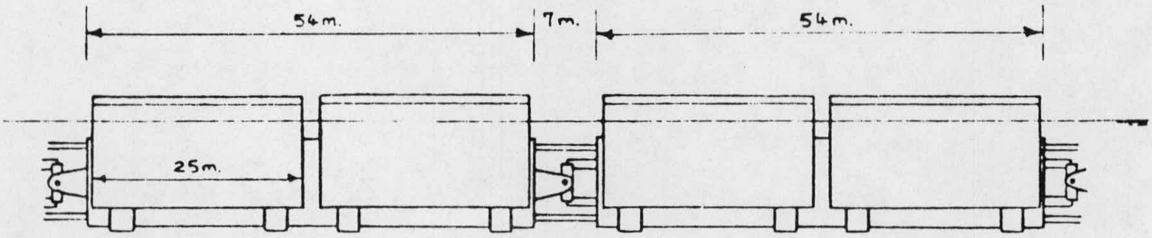


SALTER DUCK DEVICE
(Comprises two Ducks on a common Spine)



Design in concrete

Principal dimensions: Spine 60m long (including joint) 10m diameter
Ducks 25m long



Side elevation showing pairs of Ducks on their Spines.